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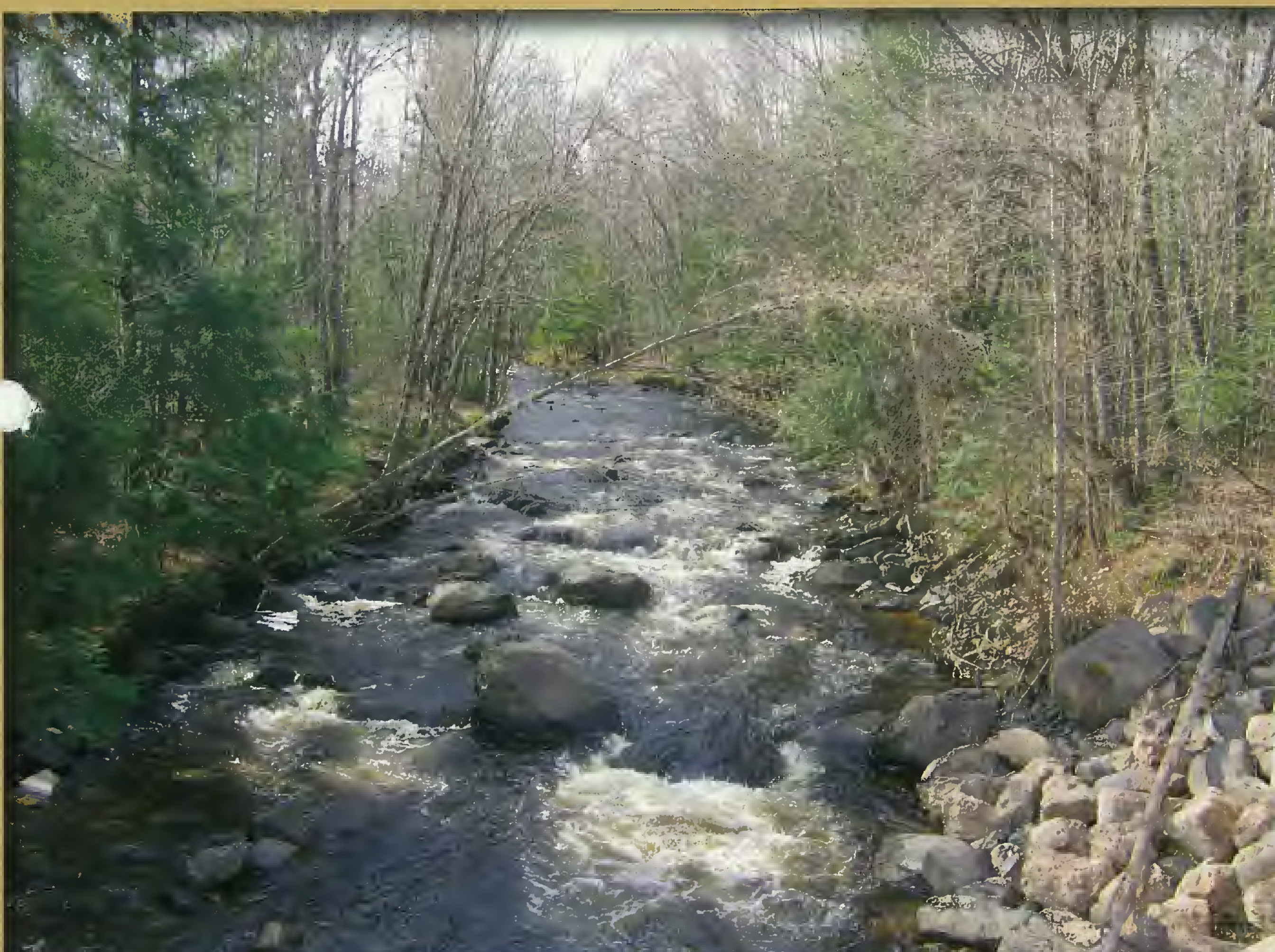
Water Quality and Hydrology of the Silver River Watershed, Baraga County, Michigan, 2005–08



Scientific Investigations Report 2010–5050

U.S. Department of the Interior
U.S. Geological Survey

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By Thomas L. Weaver, Daniel J. Sullivan, Cynthia M. Rachol, and James M. Ellis

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Abbreviations

Water year is the 12-month period from October 1 through September 30. The water year is designated by the calendar year in which it ends. For example, the year starting October 1, 2008 and ending September 30, 2009 is called the "2009 water year."

AMLE	adjusted maximum likelihood estimation
AMV	aquatic maximum value
DOC	dissolved organic carbon
FCV	final chronic value
GLEAS	Great Lakes Environmental Assessment Section
HCV	human cancer value
HNV	human non-cancerous value
KBIC	Keweenaw Bay Indian Community
LRL	laboratory reporting level
LT-MDL	long-term method detection limit
MDEQ	Michigan Department of Environmental Quality
MDL	method detection limit
MRL	minimum reporting level
NFM	national field manual
NOAA	National Oceanic and Atmospheric Administration
NWIS	National Water Information System
NWQL	National Water Quality Laboratory
QAPP	Quality-Assurance Project Plan
QA/QC	quality assurance/quality control
PAHs	polycyclic aromatic hydrocarbons
PCBs	polychlorinated biphenyls
PEC	probable effect concentration
TEC	threshold effect concentration
USEPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Survey
VA	visual accumulation
WV	wildlife value

Water Quality and Hydrology of the Silver River Watershed, Baraga County, Michigan, 2005–08

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Abstract

The Silver River Watershed comprises about 69 square miles and drains part of northeastern Baraga County, Michigan. For generations, tribal members of the Keweenaw Bay Indian Community have hunted and fished in the watershed. Tribal government and members of Keweenaw Bay Indian Community are concerned about the effect of any development within the watershed, which is rural, isolated, and lightly populated. For decades, the area has been explored for various minerals. Since 2004, several mineral-exploration firms have been actively investigating areas within the watershed; property acquisition, road construction, and subsurface drilling have taken place close to tributary streams of the Silver River.

The U.S. Geological Survey, in cooperation with Keweenaw Bay Indian Community, conducted a multi-year water-resources investigation of the Silver River Watershed during 2005–08. Methods of investigation included analyses of streamflow, water-quality sampling, and ecology at eight discrete sites located throughout the watershed. In addition, three continuous-record streamgages located within the watershed provided stage, discharge, specific conductance, and water-temperature data on an hourly basis.

Water quality of the Silver River Watershed is typical of many streams in undeveloped areas of Upper Michigan. Concentrations of most analytes typically were low, although several exceeded applicable surface-water-quality standards. Seven samples had concentrations of copper that exceeded the Michigan Department of Environmental Quality standards for wildlife, and one sample had concentrations of cyanide that exceeded the same standards. Concentrations of total mercury at all eight sampling sites exceeded the Great Lakes Basin water-quality standard, but the ratio of methylmercury to total mercury was similar to the 5 to 10 percent found in most natural waters. Concentrations of arsenic and chromium in bed sediments were near the threshold-effect concentration. A qualitative ecological assessment of fishes and macroinvertebrates showed that intolerant salmonids were present at most sampled sites, and macroinvertebrate communities were indicative of near-excellent or excellent conditions at all eight sites. This baseline information will aid in an ongoing monitoring effort designed to protect the water resources of the Silver River Watershed.

Introduction

The Silver River is located in the northeastern part of Baraga County in the Upper Peninsula of Michigan (fig. 1).

Much of the western half of the Silver River Watershed lies within the Keweenaw Bay Indian Community (KBIC) Reservation, although the majority of the land within the watershed is not tribally owned at the present time (2009). Water plays an integral role in the lives of KBIC Tribal members who have fished and hunted on Lake Superior, Keweenaw and Huron Bays, and waters in the Silver River Watershed for generations. Chippewa (or Ojibwa) Indians have lived in the northern Great Lakes Basin for centuries and have depended upon the Great Lakes and tributary streams for sustenance and transportation since their arrival.

Until recently, most water-resource management issues within the Silver River Watershed have been related to logging activities, with typical problems related to stream crossings and erosion. In 2004, however, exploration for metal-bearing deposits within the watershed began in earnest, spurred on by a worldwide surge in metal prices.

Tribal government and members of KBIC are concerned about the short-term effects of mining within the Silver River Watershed, including additional vehicular traffic, access-road building, surface-plant construction, dust, and erosion. Potential long-term effects include destruction of forests and wetland areas and degradation of water quality within the Silver River, Huron, and Keweenaw Bay Watersheds and ultimately, Lake Superior. The U.S. Geological Survey (USGS) entered into a cooperative agreement with KBIC to (1) evaluate streamflow and water quality, (2) conduct an ecological assessment of the Silver River Watershed, (3) establish a database of baseline conditions, and (4) address concerns of KBIC tribal government and members. The study was conducted during 2005–08, and the results of that effort are summarized in this report.

Purpose and Scope

The purpose of this study was to (1) sample field water-quality parameters, major ions, nutrients, trace metals, cyanide, and suspended solids from eight sites within the Silver

River Watershed during the period 2005–08; (2) establish a baseline surface-water-quality database; (3) describe generalized hydrologic and geologic characteristics of the Silver River Watershed; and (4) measure streamflow at all the sampling sites. Data from previous studies were used to augment the present study, primarily for the purpose of describing hydrology and geology of the watershed. Data collected during this study include streamflow, field water-quality parameters, water-quality samples, and quality-assurance samples at eight sites.

The study was modified somewhat in the later part of the 2008 water year, when KBIC added an ecological component to the study. Sampling of fish tissue for metals analysis and age-dating, bed-sediment sampling for size and metals analysis, and invertebrate sampling and identification were completed in August 2008; the results are summarized in this report.

Previous Studies and Data-Collection Efforts

Few studies of the Silver River Watershed are known. The USGS conducted a geochemistry study of stream sediments and groundwater wells in the Upper Peninsula of Michigan, as well as surrounding states, primarily to document the presence of uranium, but the analysis also included a number of different metals. A total of 566 stream-sediment and 611 groundwater samples were collected during 1978–79 (Smith, 1997). The USGS also conducted a study of water resources of KBIC (Sweat and Rheaume, 1998).

USGS and KBIC have cooperatively operated a continuous-record streamgage on the Silver River at Skanee Road (04043150) since October 2001 (fig. 2). A water temperature sensor was installed at the site in May 2002 and operated year-round until October 2005, when a multi-probe with water temperature and specific conductance sensors was installed. For quality-assurance and calibration purposes, the multi-probe is operated only from April through November. Stage, discharge (streamflow), specific conductance, and water-temperature data are available on the USGS National Water Information System (NWIS) website at *http://waterdata.usgs.gov/nwis.*

In October 2007, a continuous-record streamgage was installed at the downstream Gomanche Creek site at Indian Road (04043140) and in September 2008 another continuous-record streamgage was installed at the upstream Silver River site (04043126) (fig. 2). At the time of gage installation, multi-probes with water temperature and specific conductance sensors also were installed at both sites. The multi-probes have an operational period of April through November, which mimics the multi-probe at streamgage 04043150. Data for streamgages 04043126 and 04043140 also are available in the USGS NWIS database.

Michigan Technological University through its Aqua Terra Tech student enterprise group, contracted with KBIC to produce groundwater and surface-water flow models of the Silver River Watershed (France and others, 2005; Trahan and others, 2005). The major purpose of constructing the surface-water flow model appears to have been to calibrate the groundwater-flow model. There are some inconsistencies in the surface-water model that are acknowledged by the authors.

Environmental staff from KBIC have been measuring water temperature, dissolved oxygen, specific conductance, and pH, and collecting bacteriological samples at nine sites in the watershed since 1999 (fig. 2).

Several investigations of bedrock geology in the study area previously were completed. Dean Rossell of Kennecott Minerals Company prepared a concise description of their exploration at a site known as the BIC, which includes a full list of relevant geologic references in the area (Rossell, 2008).

Description of the Study Area

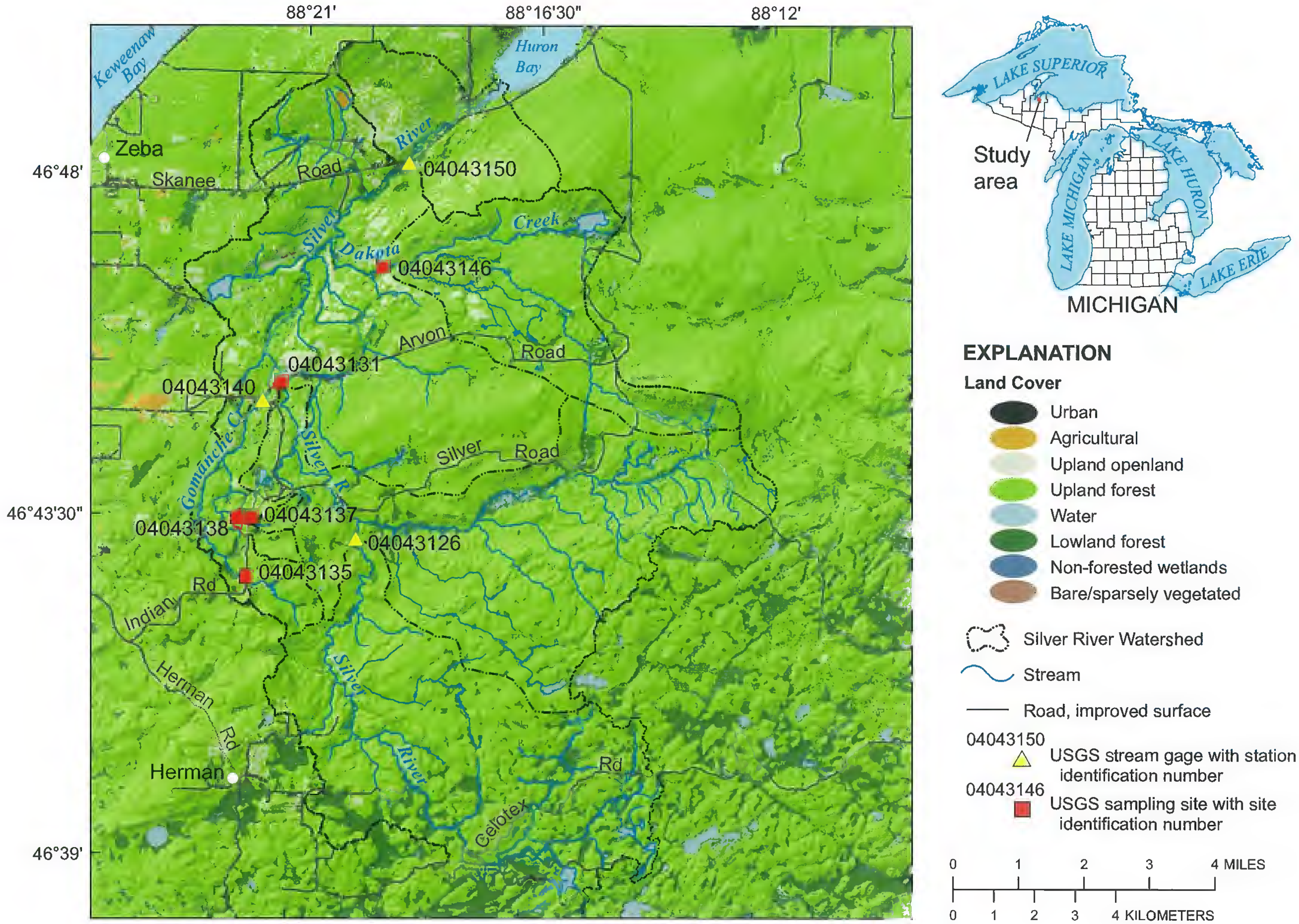
The Silver River Watershed comprises nearly 69 mi^2 located entirely within Baraga County in the Upper Peninsula of Michigan (fig. 1). The river is composed of several branches and tributaries that drain the northeastern part of the county. Most of the western half of the watershed, including the mouth at Huron Bay, is located within the traditional reservation of KBIC. Altitude of land surface within the watershed ranges from about 602 ft at the mouth to about 1,900 ft near Pages Creek in the eastern part of the watershed. The Keweenawan BIC deposit is hosted in a bedrock high that comprises the highest hill near Indian Road, at an altitude of about 1,540 ft. Branches of Gomanche Creek that drain either side of the Keweenawan BIC deposit flow beneath Indian Road at altitudes of 1,214 and 1,263 ft. High gradients are typical in parts of most of the tributary streams; several spectacular gorges, falls, and rapids cut into the Michigamme Slate are located on the Silver River between Arvon Road and the mouth.

Land cover in the study area is summarized in table 1 and shown on figure 3. No major cities are located within or near the study area, although the Village of L'Anse (fig. 1), with a population of 2,107 (2000 Census), is located several miles

Table 1. Land cover in the study area, Baraga County, Michigan (Michigan Department of Natural Resources, Forest, Mineral, and Fire Management Division, 2003).

[<, less than; numerical values in the table are rounded and total is not exactly 100 percent]

Land-cover type	Percentage of study area
Urban	0.6
Agricultural	<.1
Upland open land	5.3
Forest	92.0
Water	1.2
Wetlands	.9
Bare/sparsely vegetated	<.1



Land cover from Michigan Department of Natural Resources, 2003
Elevation data from U.S. Geological Survey, EROS data center, 1999, 1:24,000
Hydrologic divides modified from Michigan Department of Environmental Quality, 1998, 1:24,000
Hydrologic features, roads, and locations from Michigan Center for Geographic Information, 2006, 1:24,000

Figure 3. Silver River Watershed showing land cover, topographic features, and U.S. Geological Survey (USGS) surface-water gaging stations and sampling sites, Baraga County, Michigan.

Geologic Setting

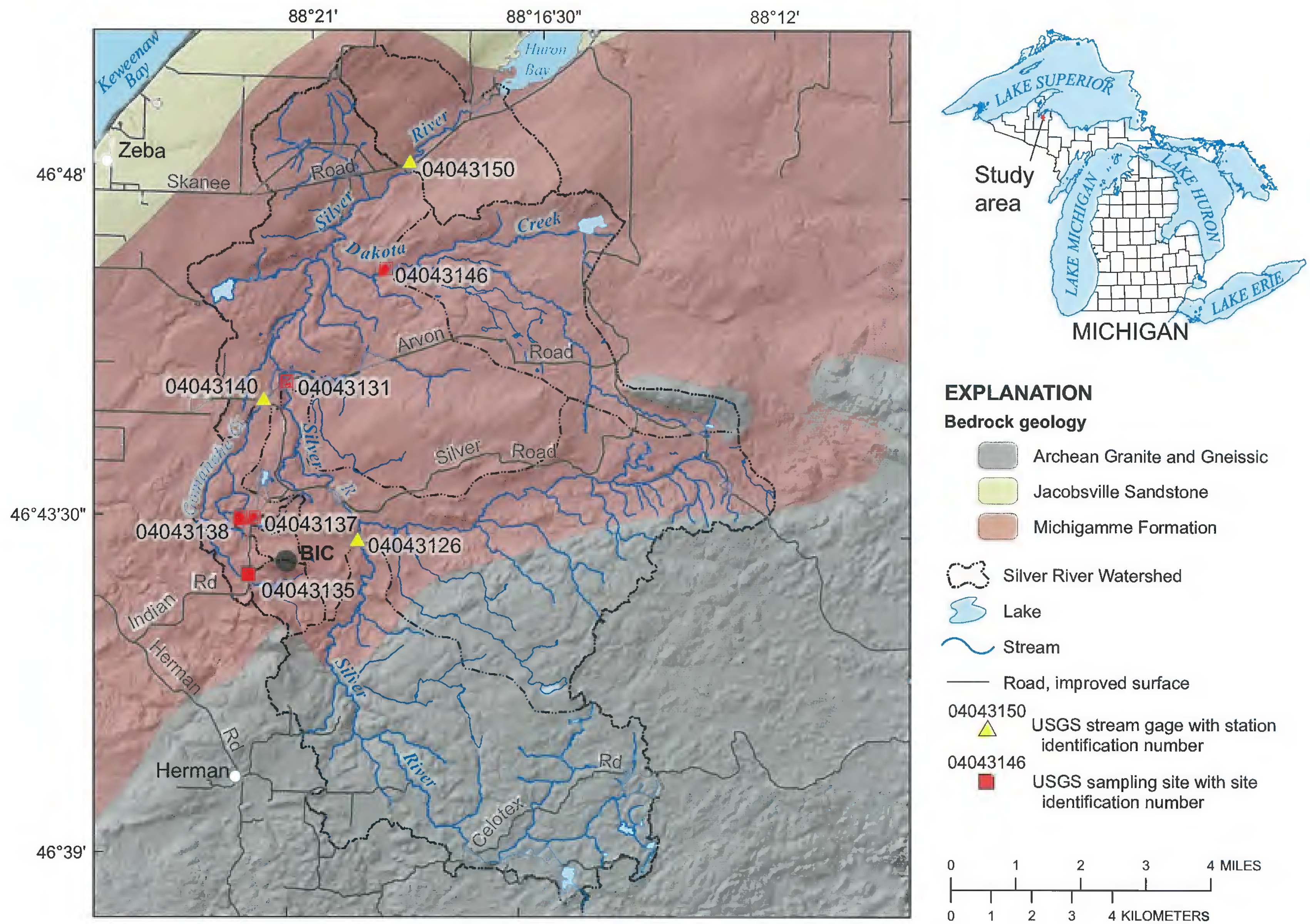
The land-surface features in Baraga County are affected by the underlying Archean and Precambrian bedrock features and unconsolidated glacial deposits, which overlie the bedrock (Doonan and Byerlay, 1973). Topography of the study area (fig. 2) is quite rugged when compared with most of Michigan. Altitude of land surface ranges from about 600 ft at the mouth of the Silver River to about 1,979 ft at Mt. Arvon, in the eastern part of the county, which is the highest point in Michigan (fig. 1).

Glacial Sediments

With the exception of some areas where bedrock outcrops at the land surface, landforms including outwash plains, moraines, and till plains created by Pleistocene glacial advance and retreat (melting) are the predominant geomorphologic features of the present-day Upper Peninsula of Michigan, including Baraga County (Farrand and Bell, 1982) (fig. 4). The glacial history of the study area is complex, similar to most other glaciated areas of the Upper Midwest. Based on numerous studies, multiple episodes of Wisconsinan-age glaciation, beginning around 75,000 years ago (Illinois State Geological Survey, 2009), are known to have occurred in the study area. Earlier glacial advances also covered the study area, but glacially derived sediments, which compose most of the present-day unconsolidated deposits overlying bedrock in the study area, are primarily attributed to late Wisconsinan readvances, which occurred as recently as 9,900 years ago. As the ice advanced from the present-day Lake Superior Basin, it formed into lobes and flowed south and west. Baraga County was covered by the Keweenaw Lobe, which was a sublobe separated from the main Superior Lobe by highlands in the Keweenaw Peninsula (fig. 1), northwest of Baraga County. The Keweenaw Lobe moved southwestward in Keweenaw Bay and then spread generally southeastward onto the highlands (Doonan and Byerlay, 1973). As the Keweenaw Lobe melted back to the position of the Keweenaw Moraine, a series of proglacial ponded-meltwater lakes formed, including the area now known as the Baraga Plains. The Marinesco Moraine, which predates the Keweenaw Moraine, trends roughly east-west, approximately parallel with and immediately south of State Highway M-28 (fig. 1), and covers the southern third of the county. A smaller, northeastward-trending landform was mapped by Leverett (1929) as the Covington Moraine. The location of the Covington Moraine is roughly parallel to the Keweenaw Moraine and simply may be a landward extension of that landform deposited during the last re-advance around 9,900 years before present. Holocene (post-glacial) sediments largely are confined to areas adjacent to surface-water bodies, including the area near the mouth of the Silver River.

Bedrock

The oldest rocks primarily are composed of Lower Precambrian granite and granitic gneiss, and Archean gneisses (Cannon and Ottke, 1999). This bedrock unit stands several hundred feet higher than surrounding bedrock formations and comprises the area called the Peshekee Uplands by Doonan and Byerlay (1973). The two highest points in Michigan, which are both in Baraga County (Mt. Arvon at about 1,979 ft and Mt. Curwood at about 1,978 ft), are both composed of this bedrock unit (fig. 1). Mt. Curwood is located within the study area, although Mt. Arvon is not. The most prolific bedrock unit in the study area is the Middle Cambrian (Animikean) Michigamme Slate, which subcrops (stratigraphically highest bedrock unit) immediately under unconsolidated sediments or outcrops (found at the surface) in the largest part of Baraga County (fig. 5). This unit appears to be a metamorphosed turbidite sequence that is primarily composed of slate, but also contains lesser amounts of quartzite, graywackes, and banded-iron formations in lower sections. The Michigamme Slate outcrops at the Silver River at Arvon Road site (site 04043131) and at the Silver River near L'Anse streamgage (04043150), where it forms the low-water control. Upper Precambrian (Keweenawan) rocks primarily composed of the Jacobsville Sandstone unit are found near the shore of Huron and Keweenaw Bays. In addition to sandstone, the Jacobsville Sandstone also contains interbedded siltstones and shales. Outcrops of Jacobsville Sandstone are visible at the shoreline along U.S. Highway 41 at L'Anse and again near Keweenaw Bay, as well as many other places on or near the shore of Lake Superior. The bedrock unit comprising the Keweenaw BIC (fig. 5) is an ultramafic/mafic intrusive body believed to be about Keweenawan age as well (Rossell, 2008). The BIC intrudes near the contact of the Archean rock and the Michigamme Formation and rises to about 300 ft more than the surrounding terrain, at an altitude of about 1,540 ft, cross-cutting the Michigamme Formation.



Bedrock geology from Michigan Department of Environmental Quality, Geologic Survey Division, 1987, 1:500,000
Elevation data from U.S. Geological Survey, EROS data center, 1999, 1:24,000
Hydrologic divides modified from Michigan Department of Environmental Quality, 1998, 1:24,000
Hydrologic features, roads, and locations from Michigan Center for Geographic Information, 2006, 1:24,000

Figure 5. Silver River Watershed showing bedrock geology, topographic features, and U.S. Geological Survey (USGS) surface-water gaging stations and sampling sites, Baraga County, Michigan.

Streamflow was measured at all sampling sites concurrent with water-quality sampling, with the exception of the Silver River at Arvon Road (site 04043131), which is very rocky and steeply graded for hundreds of feet upstream and downstream of the bridge. At medium to high streamflow, the river becomes too deep to wade and extremely turbulent near the Arvon Road bridge, precluding the prudent use of a suspended current meter as well as a depth-integrated sampler.

Standard USGS techniques were used to measure streamflow (Carter and Davidian, 1968; Rantz and others, 1982), typically with a current meter and wading rod. Each streamflow measurement was given a rating by the hydrographer, ranging from poor to excellent, which is intended to convey the accuracy of a given measurement. A number of factors are considered when rating a discharge measurement, including but not limited to characteristics of the measurement cross section, spacing and number of observation verticals, distribution of flow in the cross section, variability of velocity during the timed interval, and extent of change in stream elevation during the discharge measurement.

The USGS streamgage 04043150 at Silver River near L'Anse was established in October 2001 and was the only site within the Silver River Watershed with a stage-discharge rating during this study. A continuous-record streamgage at Gomanche Creek (04043140) was established in October 2007 but its stage-discharge rating was not fully developed until fall 2008, after all sampling for this study was complete. Typically, a stage-discharge rating is established after streamflow has been measured over a range of stage (gage height) at the site and updated as needed to reflect changes in channel configuration and control over time. A stage-discharge rating table lists a streamflow or discharge for each stage (typically in 0.1 or 0.01 ft increments). At a continuous-data streamgage with an active stage-discharge rating, such as streamgage 04043150, which records stage every hour, the calculated streamflow values are useable with an acceptable level of confidence even though they were not specifically measured, except during site visits.

Water-Quality Sampling

Water-quality data were collected using standard techniques and methods described in the USGS NFM (available online at *http://pubs.water.usgs.gov/twri9A*). Water-quality samples were analyzed at the USGS NWQL following the USGS NWQL QA/QC plan with the following exceptions: cyanide samples were analyzed by a USGS approved contract laboratory, and unfiltered total mercury and methylmercury samples collected in summer 2008 were analyzed by the USGS Wisconsin Mercury Research Laboratory in the Wisconsin Water Science Center.

Spring sampling proceeded ice out (when ice is fully melted on the streams) and was completed as soon as sites became accessible and streamflow was low enough not to damage sampling equipment. Spring sampling in all years was accomplished prior to active vegetation growth. Summer (or low-flow) sampling was accomplished after the streams reached baseflow conditions and while vegetation was still in the growth stage (before any killing frosts). Samples also were collected July 25 and 26, 2006, immediately following a quick-moving thunderstorm that dumped about 2 in. of rain on the field area (National Climatic Data Center, 2008). Field water-quality parameters (pH, specific conductance, concentration of dissolved oxygen, and water temperature) were measured using a multi-parameter meter, which was calibrated daily following the procedure outlined in the USGS NFM. Samples were collected using a proto-cleaned sampler suitable to the particular streamflow conditions at each site. In shallow, low-velocity streams, this typically was accomplished by use of a handheld grab-sample bottle (the sample bottle is held by hand below the top of the water surface), but at wadeable sites with greater depth and higher velocity streamflows, a DH81 sampler and equal-width-increment protocol were used. At unwadeable sites, typically during spring sampling, either a D-95 depth-integrated sampler or a weighted-point sampler was used. The weighted-point sampler was used only as a last resort, when turbulence or streamflow conditions precluded using the D-95 owing to concerns about equipment damage or loss (typically at site 04043131).

Water-Quality Reporting Levels and Analysis

The NWQL has established reporting levels for various analytical procedures (Oblinger-Childress and others, 1999), and this section largely is excerpted from that report. In the following sections of this report, tabulated data are reported as "uncensored," "censored," or "estimated." Uncensored data are data reported as an unqualified numerical value. Censored data are reported as less than a particular reporting level; for example, < 0.12 milligrams per liter (mg/L). Censored data result from the analyte either not being present or, if seemingly present, an inability to conclusively identify it. Estimated data are reported as qualified numerical values with an "E" before the number; for example, E0.057. Estimated values can be less than, at, or greater than the analytical reporting level. An estimated value less than the reporting level means that the analyte can be identified and measured, but with less than 99-percent confidence that it is present. Estimated values at or above the analytical reporting level can result from a poor-performance record of the analyte with the analytical method, matrix interference, or small sample volume.

Reporting levels used by the USGS NWQL are minimum reporting level (MRL), method detection limit (MDL), long-term method detection limit (LT-MDL), and laboratory reporting level (LRL). The MRL is the lowest measured concentration of an analyte that can be reliably reported. The MDL is the minimum concentration that can be measured and reported with a 99-percent confidence that the analyte is present. The LT-MDL is derived from the standard deviation of a minimum of 24 MDL spike samples over an extended period. The LRL generally is equal to twice the LT-MDL. The probability of reporting an analyte as nondetected when it is present is less in Michigan for several years and consists of separate qualitative evaluations of the fish community, macroinvertebrate community, and the habitat quality, completed in that order to minimize disruption of the sampled communities.

Sediment samples were composites of samples collected by hand with a Teflon scoop from each of 5 to 10 depositional zones (submerged during low streamflow) along a reach of approximately 150 m. Samples were collected from the upper 2 cm (most recent, oxidized layer), and the amount collected depended upon the relative size of the depositional zone. Deposits of fine-grained sediment were sought out and sampled; thus, concentrations represent conditions in depositional areas of the streams, not the average concentrations for sediment throughout the stream reach. A bulk (<2 mm fraction) sample was removed and submitted for particle-size analysis from the composited samples from each site. The remaining sediment was wet-sieved in the field, and the fine (<0.063 mm) fraction was submitted for trace-element analysis.

Methods for collection and processing of biota (Moulton and others, 2002) included use of plastic implements (Teflon, polypropylene, or polyethylene) where appropriate for trace-element sampling. Quality-control procedures for the collection and processing of biota and sediment included collection of approximately 15-percent replicate samples and the use of clean techniques to minimize potential contamination. Fish for community and tissue analyses were collected by use of direct-current electrofishing gear. Depending upon stream depth, stage, and other factors, either backpack-mounted or towed-barge electrofishing units were used. The target organism for tissue analysis was the brook trout (*Salvelinus fontinalis*). After capture, the fish were rinsed in native water, weighed, and measured for total length. Otoliths were collected for age determination. Fish fillets were removed, placed in precleaned glass jars with Teflon-lined lids, frozen on dry ice, and shipped to the laboratory for analysis.

Hydrology of the Silver River Watershed

The hydrology of the Silver River Watershed was investigated by making discrete streamflow measurements at all eight sampling sites and installing three continuous-record streamgages. Annual mean streamflow and mean annual runoff are now known for each of the continuous-record streamgages showing differences between stream segments. In addition, if loading calculations are required in the future, each water-quality sample has an associated streamflow.

Streamflow

During this study, streamflow was either measured using a current meter; acoustic Doppler velocimeter; or water-tight container of known capacity, such as a plastic 1-gal. bucket; or calculated using a stage-discharge rating concurrent with water-quality sampling at all of the data-collection sites. The results are summarized in appendix 1. In addition, streamflow has been monitored on a real-time basis at the Silver River near L'Anse streamgage (04043150) since the beginning of the study. Two additional continuous-record streamgages were established during the study period: Gomanche Creek at Indian Road (04043140) on October 31, 2007, and the Silver River upstream of the East Branch (04043126) on October 1, 2008. Historic and current stage and streamflow data from the continuous-record streamgages are available online at various USGS websites including *http://mi.water.usgs.gov* and *http://waterdata.usgs.gov/nwis/sw.*

Silver River Upstream of East Branch

The Silver River upstream of the East Branch confluence flows under a steel and timber bridge on an unnamed, unimproved road owned by Plum Creek Timber Company (fig. 2). The drainage basin includes an area of about 16.8 mi^2. The stream channel is low gradient near the bridge and upstream for several hundred feet. Tag alders and other bushes dominate the near-shore vegetation. Water-quality sampling and streamflow measurements both are easily made at this location, which has a gravel-channel bottom except near the bridge, where the channel is quite rocky, including some large boulders (fig. 6). Average runoff will be available after the stage-discharge rating is developed. A continuous-record streamflow gage and a water-quality monitor to measure water temperature and specific conductance (streamgage 04043126) were installed and made operational at this location on September 25, 2008 (fig. 7).

Silver River at Arvon Road

The drainage basin of Silver River at Arvon Road (site 04043131) includes an area of about 34.5 mi^2 (fig. 2). The site is located several miles downstream of the confluence with the East Branch Silver River and a few hundred yards upstream of the confluence with Gomanche Creek, which occurs near the center of a spectacular series of rapids and falls where both streams are deeply incised into the Michigamme Slate. Arvon Road crosses Silver River on a high-capacity modern concrete bridge demonstrative of the importance of the forest-products industry in this remote location. The reach upstream and downstream of the bridge is high-gradient and composed of numerous riffles of rocks and boulders (fig. 8). During periods of low streamflow, the area immediately downstream of the bridge is pooled behind a riffle, but the channel bottom and banks are strewn with boulders that make water-quality sampling and streamflow measuring difficult. During moderate flows, a number of the pools are suitable for water-quality sampling, although useable streamflow-measuring sections are less plentiful. During times of high runoff, sampling is difficult at this site and streamflow measurement is impossible without incurring equipment damage.

October 2001. A water-temperature sensor was installed in May 2002 and operated until October 2005 when it was replaced by a multiparameter probe measuring specific conductance and water temperature. Water-quality samples and streamflow measurements are obtained at the site by either wading or using a bridge crane and suspended D-95 sampler or current meter off the bridge. Conditions for sampling and measuring are good at all stages. Annual mean streamflow for the period 2002–08 is 82.9 ft^3/s or 1.3 $(ft^3/s)/mi^2$ of drainage area. Mean annual runoff for the period 2002–08 is 17.3 in. Water year 2008 was somewhat wetter than other years with annual runoff of 1.5 $(ft^3/s)/mi^2$ of drainage area or 20.4 in. for the year. Highest streamflow for the period of record at the site is 3,180 ft^3/s, which occurred May 12, 2003, after the dam at Lost Lake (located in the Gomanche Creek Watershed) failed during an extremely heavy, localized rainfall event. Stream stage has been higher than the underside of the bridge twice since the gage became operational. Lowest streamflow for period of record at the site is 3.5 ft^3/s, which occurred several days in mid-August 2007; lowest streamflow during 2008 was 7 ft^3/s.

Figure 6. U.S. Geological Survey hydrologic technician examining low-water control downstream of bridge at USGS streamgage 04043126 prior to ecological sampling. (Photograph by J.A. Wilkinson, U.S. Geological Survey)

Figure 7. U.S. Geological Survey streamgage at upper Silver River (04043126) during installation. (Photograph by M. A.A. Holmio, U.S. Geological Survey)

Figure 9. View looking upstream at upper Gomanche Creek at Indian Road (U.S. Geological Survey site 04043135) from Indian Road, May 10, 2005. (Photograph by T.L. Weaver, U.S. Geological Survey)

Figure 10. View looking upstream at East Branch Tributary to Gomanche Creek at Indian Road (U.S. Geological Survey site 04043137) from Indian Road, May 10, 2005. (Photograph by T.L. Weaver, U.S. Geological Survey)

Figure 13. U.S. Geological Survey streamage at Gomanche Creek at Indian Road (04043140). (Photograph by T.L. Weaver, U.S. Geological Survey)

Figure 14. Dakota Creek at unnamed logging-road crossing (U.S. Geological Survey site 04043146), May 12, 2005. (Photograph by T.L. Weaver, U.S. Geological Survey)

is reasonable to assume that nutrient levels measured during this study are representative of non-perturbed or natural "baseline" conditions.

Laboratory analyses showed concentrations of ammonia plus organic nitrogen in unfiltered water ranging from an estimated 0.06 to 0.52 mg/L at all sites except East Branch Tributary to Gomanche Creek site (04043137), which had concentrations ranging from 0.41 to 0.65 mg/L. Concentrations of nitrate plus nitrite in filtered water ranged from 0.02 to 0.23 mg/L at all sites except West Branch Tributary to Gomanche Creek (04043138), which had a concentration of 0.47 mg/L on October 31, 2007. Concentrations of total phosphorus in unfiltered water ranged from an estimated value of 0.004 to 0.05 mg/L at all sampling sites except 04043137, which had concentrations that were all less than 0.01 mg/L (0.013 to 0.086 mg/L). Concentrations of nutrients in the Silver River Watershed are low, indicating little, if any, septic-system or agricultural-waste effect in the watershed during the time of this study.

Nickel and Copper

Concentrations of nickel ranged from 0.1 to 1.57 µg/L, with the highest concentrations found in samples from the upper Silver River, East Branch Tributary to Gomanche Creek, and downstream Gomanche Creek sites. Concentrations of copper ranged from an estimated value of 0.26 to 22.9 µg/L, with the highest concentrations found in samples from the upper Silver River (22.9 µg /L) and Dakota Creek (16.3 µg /L). There appears to be a correlation between high concentrations of copper and high streamflows at the other six sites, but this was not the case at the two sites with the highest concentrations. Erosion and runoff also are highest during periods of high streamflow; however, both high-concentration samples were collected during a period of low streamflow in September 2006. One possible scenario is that the streams are in direct contact with copper-bearing geologic materials upstream of the two sites with the highest concentrations. Seven samples had concentrations of copper that exceeded the MDEQRule 57 water-quality standard aquatic-maximum value of 7.6 µg/L (Michigan Department of Environmental Quality, 2008), including three samples from the East Branch Tributary to Gomanche Creek site (04043137).

Mercury

Some streams and lakes in northern Baraga and Marquette Counties are known to have elevated concentrations of mercury in game fish, but the source of the mercury is unknown. The Michigamme Slate is known to be locally anomalously enriched in Hg with vales as high as 1.6 parts per million (ppm). Likewise, mineral prospectors have reported cinnabar from time to time. Atmospheric deposition of mercury is probably the dominant source of mercury to the Silver River Watershed although some concealed bedrock sources may also be in contact with parts of the streams. (W.F. Cannon, U.S. Geological Survey, written commun., 2009)

Investigations initiated in the late 1980s in the northern-tier states of the U.S., Canada, and Nordic countries found that fish, mainly from nutrient-poor lakes and often in very remote areas, commonly have high levels of mercury. More recent fish-sampling surveys in other regions of the U.S. have shown widespread mercury contamination in streams, wetlands, reservoirs, and lakes. To date (2009), 33 states have issued fish-consumption advisories because of mercury contamination (Krabbenhoft and Rickert, 1995). (See inset box on page 22.)

The USGS Wisconsin Water Science Center houses the Mercury Research Laboratory (USGS MRL) and team. Prior to September 2008, samples from the Silver River Watershed sites were analyzed using the mercury-analytical schedule at the USGS NWQL. The September 2008 samples were analyzed using the USGS MRL protocol and laboratory. All sites were sampled for unfiltered total mercury and methylmercury, and those results are summarized in table 8. Unfiltered samples contain both dissolved and particulate forms of mercury.

Table 8. Concentrations of total mercury and methylmercury in unfiltered water samples from the Silver River Watershed, Michigan.

[USGS, U.S. Geological Survey; SW, surface water; --, measurement not recorded; QA, quality-assurance sample; all concentrations are in nanograms per liter]

USGS station number	Parameter	Concentration of unfiltered total mercury	Concentration of unfiltered methylmercury	pH, in standard units	Ratio of methylmercury to total mercury
4043126	SW	3.44	0.38	7.5	0.11
4043131	SW	2.74	.33	7.9	.12
4043135	SW	4.52	.24	8.1	.05
4043137	SW	5.48	.25	7.9	.05
4043138	SW	2.43	.28	8.6	.12
4043140	SW	1.31	.18	--	.14
04043146	SW	1.84	.20	8.1	.11
04043146	QA	<.04	<.04	8.1	--
04043150	SW	2.43	.28	7.7	.12

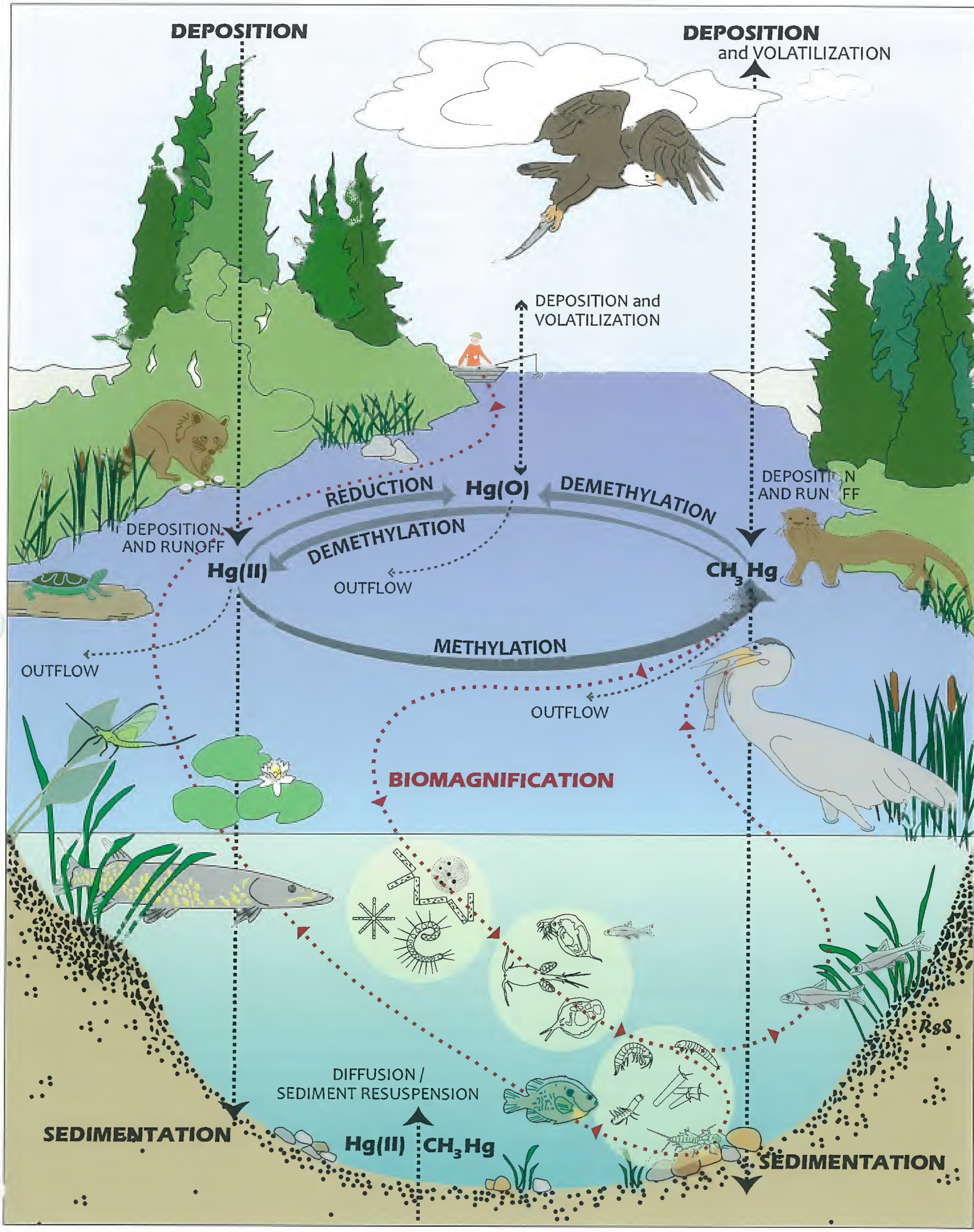


Figure 15. Aquatic mercury cycle illustrating the complexities of mercury-cycling pathways in aquatic environments.

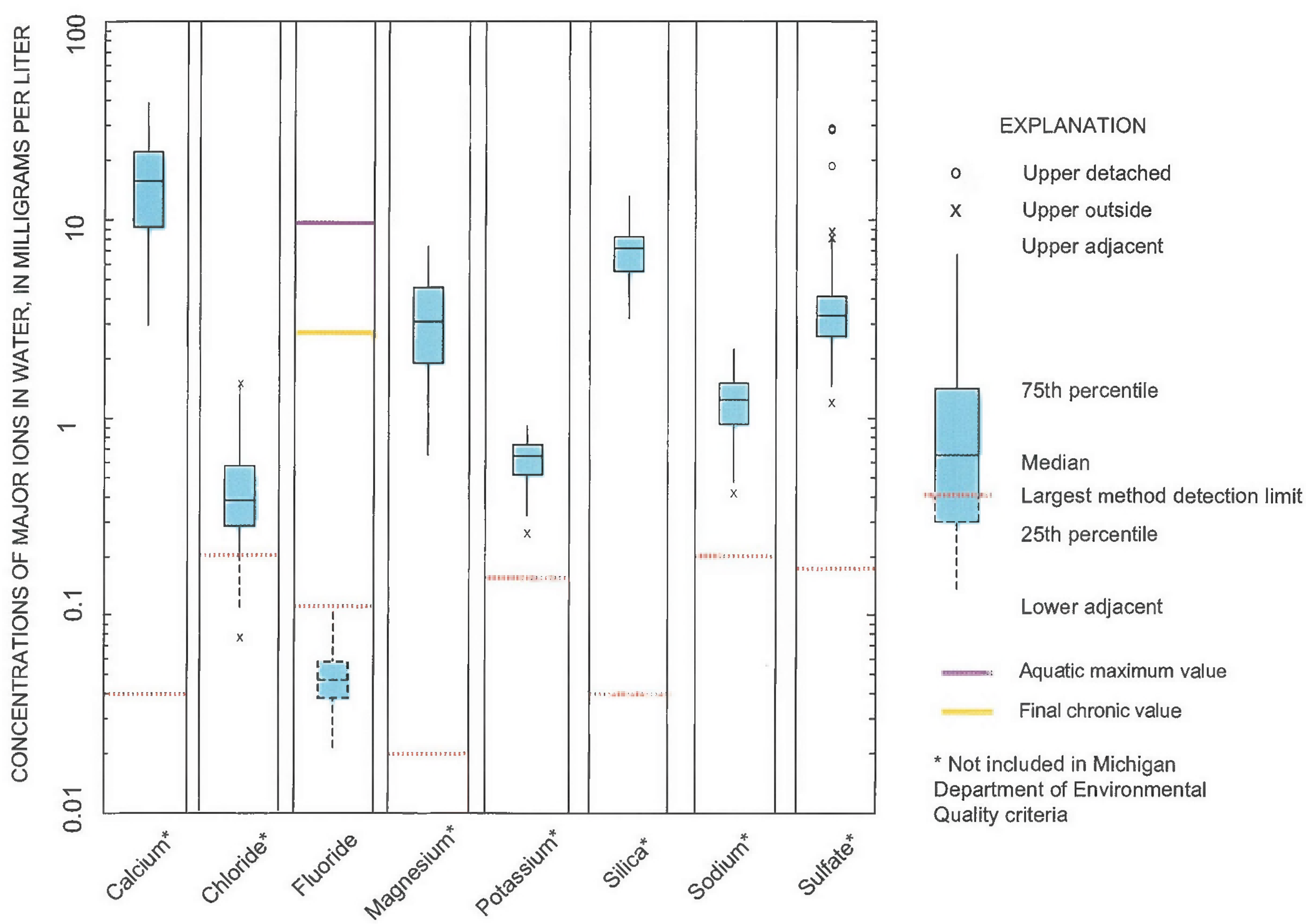


Figure 16. Concentrations of major ions in 80 water-quality samples, Silver River Watershed, Michigan, 2005-08

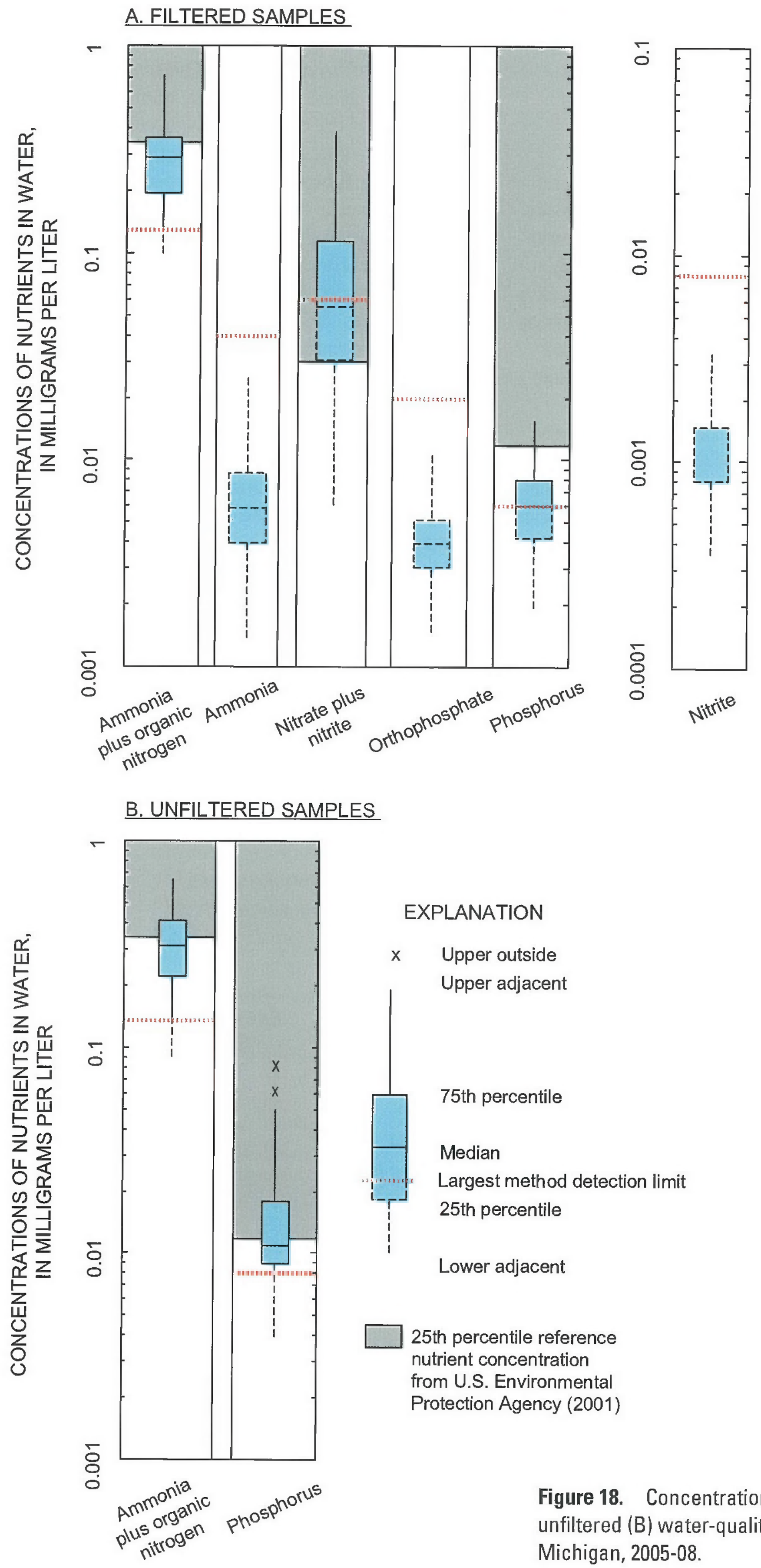


Figure 18. Concentrations of nutrients in 80 filtered (A) and unfiltered (B) water-quality samples, Silver River Watershed, Michigan, 2005-08.

As of June 2009, MDEQ had not adopted criteria for nutrients, although the USEPA had developed criteria for total nitrogen, total phosphorus, turbidity, and chlorophyll *a* (U.S. Environmental Protection Agency, 2001). Nutrient criteria have not been developed for ammonia plus organic nitrogen and nitrate plus nitrite nitrogen, though these analytes were included in this study, and 25th percentiles were reported within the USEPA's nutrient-criteria document. The USEPA recommended that these percentiles should be used as references and not specifically as water-quality criteria; however, according to Haack and Duris (2008) it is possible that these 25th-percentile values will be used if quality criteria are established in the future. Table 10 presents the 25th-percentile values for Nutrient Ecoregion VIII, subecoregion 50 streams, which include the Silver River Watershed (U.S. Environmental Protection Agency, 2001).

For the filtered samples, concentrations of nutrients in 33 of the 80 samples analyzed for ammonia plus organic nitrogen were equal to or greater than the 25th-percentile value; all but 2 of the samples analyzed for nitrate plus nitrite were equal to or exceeded the 25th-percentile value; and 2 of the 80 samples analyzed for total phosphorus were equal to or greater than the 25th-percentile value. For the unfiltered samples, 35 of the 80 samples analyzed for ammonia plus organic nitrogen were greater than the 25th-percentile value; and for samples analyzed for total phosphorus, 39 of the 80 samples were equal to or greater than the corresponding 25th-percentile values (table 9, fig. 18). Notably, 8 of 10 filtered samples and all 10 unfiltered samples collected at the East Branch Tributary to Gomanche Creek exceeded the 25th-percentile value for ammonia plus organic nitrogen criteria.

Bed-Sediments Analysis

Bed sediments were sampled at seven of the eight sites in conjunction with fish-tissue sampling in August 2008. The Silver River at Arvon Road site (04043131) was excluded owing to lack of suitable sediments at the site. Bed-sediment samples were collected and processed using methods described in the USGS NFM Chapter A8 (available online at *http://pubs.water.usgs.gov/twri9A*). The samples were analyzed for 42 metals and other selected elements at the USGS NWQL and for grain-size distribution at the Kentucky Water Science Center Sediment Laboratory.

Bed-sediment samples were composites of samples collected by hand with a Teflon scoop from each of 5 to 10 depositional zones (submerged during low streamflow) along a reach of approximately 150 m. Samples were collected from the upper 2 cm (most recent, oxidized layer), and the amount collected depended upon the relative size of the depositional zone. Deposits of fine-grained sediment were targeted for sampling; thus, concentrations represent conditions in depositional areas of the streams, not the average concentrations for sediment throughout the stream reach. A bulk <2-mm fraction was removed from the composited sample from each site for particle-size analysis. The rest of the sample was wet-sieved in the field, and the fine (<0.063 mm) fraction was collected for trace-element analysis.

Results of the metals analysis are presented in appendix 2. Notably, two sites (upstream Gomanche Creek (04043135) and Silver River near L'Anse streamgage (04043150)) did not have concentrations of any elements that ranked highest overall among the seven sites. Conversely, three sites (West Branch Tributary to Gomanche Creek (04043138), Dakota Creek (04043146), and upper Silver River (04043126)) had the highest concentrations of many of the elements (27, 11, and 8, respectively). West Branch Tributary to Gomanche Creek had the highest concentrations of mercury, uranium, vanadium, and zinc. Dakota Creek had the highest concentrations of the rare-earth elements cerium and lanthanum, as well as rubidium and cesium. The upper Silver River and West Branch Tributary to Gomanche Creek had identical concentrations of nickel, niobium, and scandium, and the West Branch Tributary to Gomanche Creek and Dakota Creek had identical concentrations of cadmium. Figure 19 illustrates statistical analyses of the concentrations of bed sediment for all but bismuth, silver, and sulfur, which were below MDLs at all sampling sites. Once again, boxplots were chosen to most concisely present the data.

Table 10. Ambient water-quality criteria for select nutrients as defined by the U.S. Environmental Protection Agency within Nutrient Ecoregion VIII, Sub-ecoregion 50 (U.S. Environmental Protection Agency, 2001).

[All values are in milligrams per liter]

	Ammonia plus organic nitrogen	Nitrate plus nitrite nitrogen	Total nitrogen	Total phosphorus
25th percentile	0.33	0.03	0.44	0.012

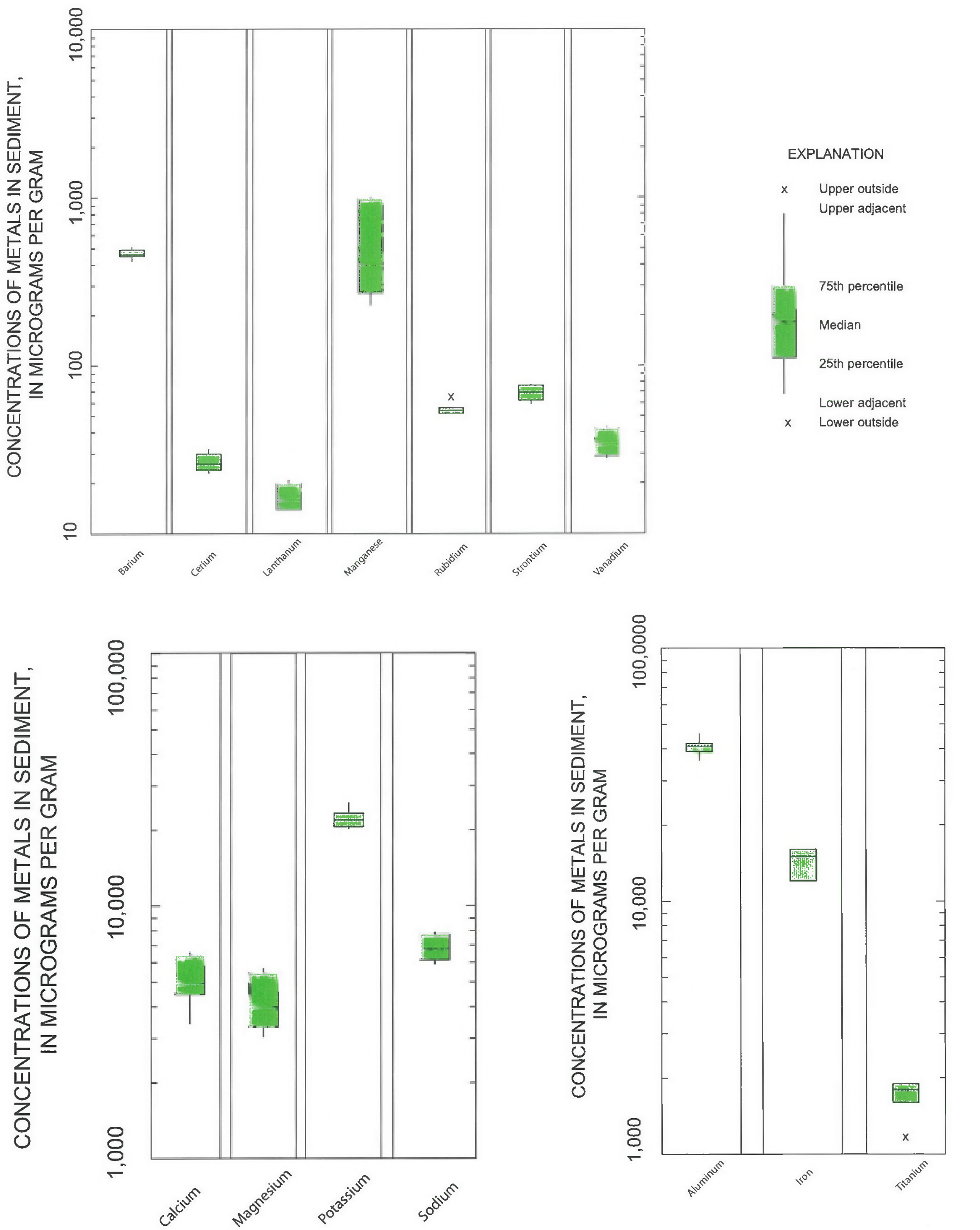


Figure 19. Concentration of metals in seven bed-sediment quality samples, Silver River Watershed, Michigan, 2005-08.—Continued

Grain-Size Distribution

Analysis of grain-size distribution over time provides an important measure of physical changes within a watershed. Erosion and mass wasting, both natural and anthropogenic, can result in considerable changes in grain-size distribution within a watershed. This can occur gradually or catastrophically, depending upon the sediment source(s) being introduced into the stream.

Results of the grain-size distribution of bed sediments are shown in table 12. The silt and clay-size fraction (all sediments <0.063 mm) composed about 20 percent or less of the analyzed sediments in all of the streams and less than 7 percent in three streams (upper and lower Gomanche Creek (04043135 and 04043140, respectively) and East Branch Tributary to Gomanche Creek (04043137)). All sites except Dakota Creek (04043146) and Silver River near L'Anse (04043150) had visual accumulation (VA)-tube fractions (grain size 0.063 to 1.0 mm) ranging from about 71 to 87 percent. The laboratory noted that not enough sample material was available for either of those sites and the VA tube was not used. It is noteworthy that all the streams have 20 percent or less silt/clay-sized materials, demonstrative of the high gradient typical throughout the watershed, which rapidly washes any fine-grained sediment out of the system.

Ecological Investigation

An ecological investigation of the Silver River sites that complements other parts of this study was conducted during August–September 2008. The investigation was completed using a modified version of the MDEQ GLEAS procedure 51, which is a qualitative-biological and habitat-survey protocol for wadeable streams that has been employed extensively in Michigan for several years (Michigan Department of Environmental Quality, 2007). The GLEAS 51 protocol consists of separate qualitative evaluations of the fish community, the macroinvertebrate community, and the habitat quality, completed in that order to minimize disruption of the sampled communities. The study team and KBIC Natural Resources Department chose the GLEAS 51 procedure for ease of application and comparison with other streams throughout the Upper Peninsula previously surveyed by the MDEQ. In the GLEAS 51 procedure, each survey station is described by up to three numbers or metrics; one each for the fish, macroinvertebrates, and habitat. An excellent-quality stream for the ecoregion would have the most metrics performing like an excellent site, while a poor-quality stream would have substantially different metrics. Use of metrics creates a uniform and systematic evaluation for each site with the result expressed as a single numerical value that easily is comparable to other sites. For this study, the habitat-assessment part of the GLEAS 51 procedure was not completed owing to budget constraints, as well as to the unaltered, inaccessible condition of most of the watershed.

Fishes

Much of the Silver River Watershed primarily is a coldwater fishery, with one or more species of salmonids present at several of the sampling sites. The GLEAS 51 protocol for coldwater fisheries is much simpler than for warm-water fisheries. Target streams are evaluated for the presence of at least 50 fish and the relative abundance of anomalies and salmonids collected (Michigan Department of Environmental Quality, 2007). For this study, the fish community part of the GLEAS 51 procedure was modified, targeting a single intolerant fish species (brook trout) as described in the next paragraph, although all shocked fish in each sampling reach were measured and identified. After a thorough reconnaissance of all eight water-quality sampling sites, the USGS and KBIC elected to sample reaches at the following four sites: upstream Silver River (04043126), Gomanche Creek (04043140), Dakota Creek (04043146), and Silver River near L'Anse (04043150). A summary of fish communities collected at the four sites is shown in table 13. Additional sites downstream of Silver River at Arvon Road (04043131) and upstream and downstream of Silver River near L'Anse streamgage (04043150) also were sampled, but stream conditions at those locations were either poor (no fish habitat) or channel composition (depths; high gradients; channels composed entirely of slaty bedrock) made electrofishing difficult to impossible.

USGS and KBIC crews used a combination of backpack and barge-shocking units to conduct the survey, targeting native (not hatchery stocked) 3- to 4-year-old brook trout (*Salvelinus fontinalis*), with some success in Gomanche Creek (two fish) and Dakota Creek (three fish). Low-conductivity

Table 12. Bed-sediment grain-size distribution for selected sites in the Silver River Watershed, Michigan.

[All values are in percent of total; silt/clay is grain sizes less than 0.063 mm; visual accumulation tube is grain sizes 0.063 to 1.0 millimeter; sieve is grain sizes 1.0 to 4.0 millimeters]

	U.S. Geological Survey site number						
	4043126	4043135	4043137	4043138	4043140	4043146	4043150
Silt/clay	12.3	4.5	5.7	20.2	15.4	11.1	6.5
Visual accumulation tube	83.1	70.8	86.6	73.2	82	0	0
Sieve	4.6	24.7	7.7	6.6	2.6	88.9	93.5

Table 14. Concentrations of trace-elements in brook-trout tissue samples taken from the Silver River Watershed, Michigan.

[ID, identification; <, less than; all concentrations in micrograms per kilogram]

Property or constituent	Concentration				
Lab number	T8060-001	T8060-002	T8060-003	T8060-004	T8060-005
Sample ID	1A	1B	2A	2B	2C
Stream name	Dakota	Dakota	Gomanche	Gomanche	Gomanche
Metals					
Silver	<0.00955	<0.00965	<0.00955	<0.00938	<0.00966
Arsenic	1.1	1.29	2.98	1.81	1.38
Boron	<.478	<.482	<.477	<.469	<.483
Barium	.124	<.096	.449	.094	<.097
Beryllium	<.0478	<.0482	<.0477	<.0469	<.0483
Calcium	497	647	657	555	612
Cadmium	<.0191	<.0193	.0204	<.0188	<.0193
Cobalt	<.0191	<.0193	<.0191	<.0188	<.0193
Chromium	.251	<.193	.192	<.188	<.193
Copper	1.74	1.53	9.82	1.86	1.74
Iron	21.8	20.7	23.4	14.6	11
Mercury	.661	.553	.451	.373	.409
Potassium	18,700	18,500	19,300	17,100	18,500
Magnesium	1,280	1,320	1,410	1,310	1,340
Manganese	.592	.656	1.11	.769	.686
Molybdenum	<.0955	<.0965	<.0955	<.0938	<.0966
MOIST-Grav	74.4	76.2	68.4	71.5	68.5
Sodium	1,110	1,100	1,260	1,150	1,010
Nickel	.131	<.0965	<.0955	<.0938	<.0966
Phosphorus	10,700	10,800	11,200	10,500	10,800
Lead	.103	.0911	.128	.0563	.0673
Sulfur	8,580	8,920	9,110	8,490	8,400
Antimony	<.0478	<.0482	<.0477	<.0469	<.0483
Selenium	1.91	1.65	2.09	2.16	1.94
Silicon	8.81	7.67	15.7	9.57	9.14
Tin	<.0955	<.0965	<.0955	<.0938	<.0966
Strontium	.306	.328	.449	.272	.299
Titanium	6.02	4.22	2.99	2.15	1.98
Thallium	<.00955	<.00965	<.00955	<.00938	<.00966
Vanadium	<.478	<.482	<.477	<.469	<.483
Zinc	35	35.6	47.8	37.5	36.6

Summary and Conclusions

The U.S. Geological Survey, in cooperation with Keweenaw Bay Indian Community, conducted a study during 2005–08 to (1) evaluate baseline hydrology and water quality, (2) conduct an ecological assessment of the Silver River Watershed, and (3) address tribal concerns. Streamflow was measured; water-quality samples were collected; and an ecological assessment was conducted at eight locations within the central and western parts of the 69-square mile Silver River Watershed. The U.S. Geological Survey and Keweenaw Bay Indian Community cooperatively operate three real-time streamgages and water-quality monitors within the watershed; two were installed as a complement to this study. Water-quality sampling was done 2 to 3 times per year, including, at a minimum, once shortly after ice-out in the spring and once during the summer baseflow period. Additional samplings during the year were coordinated by the U.S. Geological Survey and Keweenaw Bay Indian Community to encompass different runoff and streamflow scenarios, for example, immediately following a heavy summer precipitation event in 2006.

The water-quality characteristics of the streams within the Silver River Watershed are typical of many streams flowing through sparsely populated areas in the central Upper Peninsula of Michigan. Of note, seven samples had copper concentrations exceeding Michigan wildlife standards, and one sample had concentrations of cyanide that exceeded the same standards. Concentrations of total mercury at all eight sampling sites, from a low-flow sampling in 2008, exceeded the Great Lakes Basin water-quality standards, but the ratio of methylmercury to total mercury was similar to the 5 to 10 percent typical in most natural waters. Concentrations of arsenic and chromium in bed sediments were near the threshold-effect concentration. An ecological assessment analyzing fish and macroinvertebrate communities, by use of a modified version of the Michigan Department of Environmental Quality Great Lakes Environmental Assessment Section 51procedure, was conducted in 2008. Numbers of intolerant, coldwater salmonids were noted at all but one sampling site, and six of the eight sites scored excellent for their macroinvertebrate communities (the remaining two sites scored slightly less than excellent).

Additional water-quality data were collected by the U.S. Geological Survey and Keweenaw Bay Indian Community during 2009, and all three real-time streamflow-gaging and water-quality monitoring sites continue to operate. This report will aid in an ongoing monitoring effort designed to protect the water resources of the Silver River Watershed.

Acknowledgments

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Appendixes

Appendix 1A. Physical properties and concentrations of major elements, solids, nutrients, metals, suspended solids, and cyanide, Silver River upstream from East Branch near L'Anse, Baraga County, Michigan.—Continued

[ft³/s, cubic foot per second; E, estimated value; unfil, unfiltered; mg/L, milligrams per liter; µs/cm, microseimens per centimeter; °C, degrees Celsius; fil, filtered; $CaCO_3$, calcium carbonate; <, less than; --, no data; N, nitrogen; P, phosphorous; µg/L, micrograms per liter; mm, millimeter; N.D., analyte not detected at method detection limit]

Property or constituent		U.S. Geological Survey station 04043126									
Sampling date		5/12/2005	7/27/2005	4/19/2006	7/26/2006	9/12/2006	4/24/2007	7/25/2007	9/12/2007	10/31/2007	4/24/2008
Record number		501159	501600	600154	601531	602668	700670	701614	702328	800002	800225
Metals											
Aluminum, fil	µg/L	57	14.9	95	19.6	12.6	152	10.9	9	114	136
Antimony, fil	µg/L	<.20	<.20	<.20	<.20	<.20	E.05	E.05	E.05	<.14	<.14
Arsenic, fil	µg/L	.6	1.3	.35	1.2	1.1	.37	1.7	1.2	.71	.3
Barium, fil	µg/L	8	10	7	14	15	7	12	10	9	5
Beryllium, fil	µg/L	<.06	<.06	<.06	<.06	<.06	<.06	<.06	<.06	.01	.01
Cadmium, fil	µg/L	<.04	<.04	E.02	E.03	.06	E.03	<.04	<.04	<.04	E.04
Chromium, fil	µg/L	<.8	<.8	.24	.18	.18	.27	.16	.18	.34	.27
Cobalt, water, fil	µg/L	.072	.081	.068	.05	.05	.06	.05	.04	.08	.07
Copper, water, fil	µg/L	.9	.6	4.6	9.1	22.9	5.9	.67	E.36	1.1	1.1
Iron, fil	µg/L	191	179	146	118	118	157	156	180	301	120
Lead, water, fil	µg/L	.11	.08	.22	.57	1.17	.33	E.07	<.12	.14	.17
Manganese, fil	µg/L	14.8	14.9	7.4	16.4	11	7.8	19.2	11.6	20.2	8.8
Mercury, fil	µg/L	<.010	<.010	<.010	<.010	<.010	E.005	<.010	<.010	<.010	
Molybdenum, fil	µg/L	<.4	E.4	<.4	E.4	.4	<.1	.5	.4	E.1	<.2
Nickel, fil	µg/L	.38	.94	.67	.5	1.4	.43	.24	.31	.42	.48
Selenium, fil	µg/L	<.4	<.4	E.06	E.07	E.04	E.06	E.07	.09	.1	.09
Silver, fil	µg/L	<.2	<.2	<.2	<.2	<.2	<.1	<.1	<.1	<.1	<.1
Zinc, fil	µg/L	1.2	.8	3.3	5.1	14.7	3.8	1.9	1.1	E1.7	4.7
Uranium (natural), fil	µg/L	.05	.1	E.03	.08	.11	E.03	.09	.1	.05	.02
Suspended sediment											
Suspended sediment, sieve diameter	Percent <0.063 mm	--	--	--	--	--	--	--	62	77	--
Suspended sediment concentration	mg/L	--	--	--	--	--	--	--	3	4	--
Cyanide	mg/L	N.D.	N.D.	N.D.	N.D.	E.0030	N.D.	N.D.	N.D.	N.D.	--

Appendix 1B. Physical properties and concentrations of major elements, solids, nutrients, metals, suspended solids, and cyanide, Silver River at Arvon Road near L'Anse, Baraga County, Michigan.—Continued

[ft³/s, cubic foot per second; E, estimated value; unfil, unfiltered; mg/L, milligrams per liter; µs/cm, microseimens per centimeter; °C, degrees Celsius; fil, filtered; $CaCO_3$, calcium carbonate; <, less than; --, no data; N, nitrogen; P, phosphorous; µg/L, micrograms per liter; mm, millimeter; N.D., analyte not detected at method detection limit]

Property or constituent		U.S. Geological Survey station 04043131									
Sampling date		**5/11/2005**	**7/27/2005**	**4/20/2006**	**7/26/2006**	**9/12/2006**	**4/24/2007**	**7/25/2007**	**9/11/2007**	**10/30/2007**	**4/24/2008**
Record number		**501157**	**501597**	**600155**	**601529**	**602666**	**700668**	**701613**	**702325**	**800004**	**800223**
Metals											
Aluminum, fil	µg/L	37.3	9.6	73.9	15.4	4.4	117	6	8.3	93.7	109
Antimony, fil	µg/L	<.20	<.20	<.20	<.20	E.13	.07	E.05	E.05	<.14	E.08
Arsenic, fil	µg/L	.5	.9	.36	.85	.86	.36	1.1	.97	.56	.31
Barium, fil	µg/L	7	10	6	12	12	6	12	10	7	6
Beryllium, fil	µg/L	<.06	<.06	<.06	<.06	<.06	<.06	<.06	<.06	.01	.01
Cadmium, fil	µg/L	E.03	<.04	E.03	E.03	<.04	E.03	<.04	<.04	E.02	E.03
Chromium, fil	µg/L	<.8	<.8	.2	.15	.12	.26	.13	.13	.29	.25
Cobalt, water, fil	µg/L	.054	.068	.061	E.03	.07	.06	E.03	E.04	.06	.06
Copper, water, fil	µg/L	.8	.5	2.1	6.8	3.8	4.5	.65	.42	E.89	8.1
Iron, fil	µg/L	151	103	132	83	91	145	56	138	243	115
Lead, water, fil	µg/L	E.06	<.08	.12	.23	.15	.2	E.06	<.12	.11	.26
Manganese, fil	µg/L	6.9	2.3	5.9	7.4	2.6	5.7	3.7	3	12.4	6
Mercury, fil	µg/L	<.010	<.010	<.010	<.010	<.010	<.010	<.010	<.010	<.010	<.010
Molybdenum, fil	µg/L	<.4	E.4	<.4	E.3	.4	<.1	.5	.4	E.1	<.2
Nickel, fil	µg/L	.34	.94	.66	.52	.24	.43	.24	.28	.34	.45
Selenium, fil	µg/L	<.4	<.4	E.06	.08	E.05	.09	E.05	.08	.09	.08
Silver, fil	µg/L	<.2	<.2	<.2	<.2	<.2	<.1	<.1	<.1	<.1	<.1
Zinc, fil	µg/L	1	E.4	2.5	3.8	1.6	3.7	1.2	1.5	2.2	4.3
Uranium (natural), fil	µg/L	E.04	.09	E.03	.06	.14	E.03	.09	.09	.04	02
Suspended sediment											
Suspended sediment, sieve diameter	Percent <0.063 mm	--	--	--	--	--	--	--	75	85	--
Suspended sediment concentration	mg/L	--	--	--	--	--	--	--	1	6	--
Cyanide	mg/L	N.D.	E.0026	N.D.	N.D.	E.0036	E.0029	N.D.	N.D.	N.D.	--

Appendix 1*C*. Physical properties and concentrations of major elements, solids, nutrients, metals, suspended solids, and cyanide, upper Gomanche Creek at Indian Road near Herman, Baraga County, Michigan.—Continued

[ft^3/s, cubic foot per second; E, estimated value; unfil, unfiltered; mg/L, milligrams per liter; µs/cm, microseimens per centimeter; °C, degrees Celsius; fil, filtered; $CaCO_3$, calcium carbonate; <, less than; --, no data; N, nitrogen; P, phosphorous; µg/L, micrograms per liter; mm, millimeter; N.D., analyte not detected at method detection limit]

Property or constituent		U.S. Geological Survey station 04043135									
Sampling date		**5/10/2005**	**7/26/2005**	**4/18/2006**	**7/25/2006**	**9/11/2006**	**4/23/2007**	**7/24/2007**	**9/11/2007**	**10/31/2007**	**4/23/2008**
Record number		**501152**	**501595**	**600148**	**601525**	**602662**	**700664**	**701609**	**702321**	**800006**	**800218**
Metals											
Aluminum, fil	µg/L	27.7	11.3	34.8	13.1	4.7	59	5.7	7.1	58.8	114
Antimony, fil	µg/L	<.20	<.20	<.20	<.20	<.20	.06	E.04	E.06	<.14	<.14
Arsenic, fil	µg/L	.7	1.4	.59	1.2	1.1	.58	1.4	1.1	.76	.37
Barium, fil	µg/L	11	13	8	12	11	9	14	16	10	7
Beryllium, fil	µg/L	<.06	<.06	<.06	<.06	<.06	<.06	<.06	<.06	E.01	E.01
Cadmium, fil	µg/L	<.04	<.04	<.04	<.04	<.04	<.04	<.04	<.04	<.04	E.03
Chromium, fil	µg/L	<.8	<.8	.21	.14	.12	.3	E.09	.12	.29	.28
Cobalt, water, fil	µg/L	.059	.106	.054	.05	.04	.05	E.02	.04	.05	.05
Copper, water, fil	µg/L	1.2	.5	2.5	1.7	.68	5.3	E.36	.58	1.4	1.5
Iron, fil	µg/L	137	108	135	192	50	120	56	77	167	86
Lead, water, fil	µg/L	E.06	<.08	.08	E.05	<.08	.25	<.12	<.12	E.06	E.04
Manganese, fil	µg/L	9.9	42.1	6.4	26.6	35.6	5.5	38.8	31.1	17	4.1
Mercury, fil	µg/L	<.010	<.010	<.010	<.010	<.010	<.010	<.010	<.010	<.010	E.007
Molybdenum, fil	µg/L	E.3	.7	E.2	E.3	.5	.2	.6	.4	.4	E.1
Nickel, fil	µg/L	.65	1.48	.94	.45	.21	.61	.18	.43	.56	.51
Selenium, fil	µg/L	<.4	<.4	E.07	E.07	.08	.09	E.04	.08	.1	.09
Silver, fil	µg/L	<.2	<.2	<.2	<.2	<.2	<.1	<.1	<.1	<.1	<.1
Zinc, fil	µg/L	.9	.6	1.3	.93	<.60	3	.74	1.8	<1.8	E1.5
Uranium (natural), fil	µg/L	.09	.29	.06	.08	.39	.06	.41	.16	.09	.05
Suspended sediment											
Suspended sediment, sieve diameter	Percent <0.063 mm	--	--	--	--	--	--	--	77	83	--
Suspended sediment concentration	mg/L	--	--	--	--	--	--	--	4	2	--
Cyanide	mg/L	N.D.	N.D.	N.D.	E.0046	N.D.	N.D.	N.D.	N.D.	N.D.	--

Appendix 1*D*. Physical properties and concentrations of major elements, solids, nutrients, metals, suspended solids, and cyanide, East Branch Tributary to Gomanche Creek at Indian Road near Herman, Baraga County, Michigan.—Continued

[ft^3/s, cubic foot per second; E, estimated value; unfil, unfiltered; mg/L, milligrams per liter; µs/cm, microseimens per centimeter; °C, degrees Celsius; fil, filtered; $CaCO_3$, calcium carbonate; <, less than; --, no data; N, nitrogen; P, phosphorous; µg/L, micrograms per liter; mm, millimeter; N.D., analyte not detected at method detection limit]

Property or constituent		U.S. Geological Survey station 04043137									
Sampling date		5/10/2005	7/26/2005	4/18/2006	7/25/2006	9/11/2006	4/23/2007	7/24/2007	9/11/2007	10/31/2007	4/23/2008
Record number		501153	501596	600150	601527	602664	700666	701611	702322	800008	800220
Metals											
Aluminum, fil	µg/L	26.5	9.8	54.6	15.2	14	62.4	6.2	11.4	88.1	121
Antimony, fil	µg/L	<.20	<.20	<.20	<.20	<.20	.06	<.06	E.06	<.14	<.14
Arsenic, fil	µg/L	.4	.9	.39	.75	.87	.38	67	.63	.55	.32
Barium, fil	µg/L	10	15	9	13	19	10	18	17	10	6
Beryllium, fil	µg/L	<.06	<.06	<.06	<.06	<.06	<.06	<.06	<.06	.02	.01
Cadmium, fil	µg/L	<.04	<.04	E.03	E.03	<.04	E.03	E.02	<.04	E.02	E.03
Chromium, fil	µg/L	<.8	<.8	.21	.12	.11	.27	E.08	.13	.39	.32
Cobalt, water, fil	µg/L	.064	.144	.056	.06	.1	.04	.07	.08	.05	.04
Copper, water, fil	µg/L	.6	E.3	7.8	11.1	6.6	10.2	E.26	.41	1.2	1.1
Iron, fil	µg/L	119	339	113	192	177	112	147	148	248	128
Lead, water, fil	µg/L	E.04	E.05	.29	.43	.37	.29	<.12	<.12	E.08	E.07
Manganese, fil	µg/L	15.1	126	5.9	39.1	158	5.7	152	92.2	19.7	3.1
Mercury, fil	µg/L	<.010	<.010	<.010	<.010	<.010	<.010	<.010	<.010	<.010	E.006
Molybdenum, fil	µg/L	<.4	E.3	<.4	<.4	E.2	.1	.4	.2	E.2	E.1
Nickel, fil	µg/L	.49	1.16	1.06	.73	.38	.57	.18	.3	.57	.32
Selenium, fil	µg/L	<.4	<.4	E.06	.08	E.06	.11	<.08	E.07	.14	.08
Silver, fil	µg/L	<.2	<.2	<.2	<.2	<.2	<.1	<.1	<.1	<.1	<.1
Zinc, fil	µg/L	1.1	.9	4	7.3	3.3	5.4	1.2	1.8	E1.5	2.3
Uranium (natural), fil	µg/L	E.02	.07	E.02	E.02	.1	E.03	.11	.05	.05	.03
Suspended sediment											
Suspended sediment, sieve diameter	Percent <0.063 mm	--	--	--	--	--	--	--	71	75	--
Suspended sediment concentration	mg/L	--	--	--	--	--	--	--	2	1	--
Cyanide	mg/L	N.D.	E.0058	N.D.	N.D.	N.D.	E.0025	N.D. at 1350 N.D. at 1400	N.D.	N.D.	--

Appendix 1E. Physical properties and concentrations of major elements, solids, nutrients, metals, suspended solids, and cyanide, West Branch Tributary to Gomanche Creek near Herman, Baraga County, Michigan.—Continued

[ft³/s, cubic foot per second; E, estimated value; unfil, unfiltered; mg/L, milligrams per liter; µs/cm, microseimens per centimeter; °C, degrees Celsius; fil, filtered; $CaCO_3$, calcium carbonate; <, less than; --, no data; N, nitrogen; P, phosphorous; µg/L, micrograms per liter; mm, millimeter; N.D., analyte not detected at method detection limit]

Property or constituent		U.S. Geological Survey station 04043138									
Sampling date		**5/11/2005**	**7/26/2005**	**4/18/2006**	**7/25/2006**	**9/11/2006**	**4/23/2007**	**7/24/2007**	**9/11/2007**	**10/31/2007**	**4/23/2008**
Record number		**501156**	**501598**	**600149**	**601526**	**602663**	**700665**	**701610**	**702324**	**800007**	**800219**
Metals											
Aluminum, fil	µg/L	39.5	14.8	60.7	25.1	11.8	82.1	9.7	12.4	77.5	101
Antimony, fil	µg/L	<.20	<.20	<.20	<.20	<.20	E.05	E.04	.07	<.14	<.14
Arsenic, fil	µg/L	.3	.8	.3	.68	.67	.32	.85	.53	.42	.28
Barium, fil	µg/L	8	11	7	11	10	7	12	13	9	6
Beryllium, fil	µg/L	<.06	<.06	<.06	<.06	<.06	<.06	<.06	<.06	.01	<.01
Cadmium, fil	µg/L	<.04	<.04	E.02	<.04	<.04	E.02	<.04	<.04	<.04	E.03
Chromium, fil	µg/L	<.8	<.8	.21	.2	.22	.29	.13	.19	.3	.25
Cobalt, water, fil	µg/L	.047	.102	.051	.04	.04	.04	.05	.04	.04	.04
Copper, water, fil	µg/L	1.5	.5	6.7	3.9	5.7	2.2	.47	.81	2.6	1.5
Iron, fil	µg/L	92	121	57	70	51	69	90	52	76	55
Lead, water, fil	µg/L	E.05	<.08	.37	.14	.3	<.12	<.12	<.12	<.08	E.04
Manganese, fil	µg/L	10.3	39.8	4.2	9	13.2	3.1	35.9	15.7	7.2	1.8
Mercury, fil	µg/L	<.010	<.010	<.010	<.010	<.010	E.006	<.010	<.010	<.010	E.008
Molybdenum, fil	µg/L	<.4	E.2	<.4	E.2	<.4	.1	.2	.2	E.2	E.1
Nickel, fil	µg/L	.34	.91	1.04	.39	.31	.36	.12	.28	.35	.31
Selenium, fil	µg/L	<.4	<.4	.09	.12	E.05	.14	<.08	.08	.15	.09
Silver, fil	µg/L	<.2	<.2	<.2	<.2	<.2	<.1	<.1	<.1	<.1	<.1
Zinc, fil	µg/L	1.5	E.5	5.6	1.7	2.9	1.4	4.8	3.2	2.7	E1.4
Uranium (natural), fil	µg/L	E.04	.08	.04	.05	.08	.06	.06	E.04	.07	05
Suspended sediment											
Suspended sediment, sieve diameter	Percent <0.063 mm	--	--	--	--	--	--	--	55	50	--
Suspended sediment concentration	mg/L	--	--	--	--	--	--	--	3	2	--
Cyanide	mg/L	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	E.0025	N.D.	N.D.	--

Appendix 1F. Physical properties and concentrations of major elements, solids, nutrients, metals, suspended solids, and cyanide, Gomanche Creek at Indian Road near L'Anse, Baraga County, Michigan.—Continued

[ft^3/s, cubic foot per second; E, estimated value; unfil, unfiltered; mg/L, milligrams per liter; µs/cm, microseimens per centimeter; °C, degrees Celsius; fil, filtered; $CaCO_3$, calcium carbonate; <, less than; --, no data; N, nitrogen; P, phosphorous; µg/L, micrograms per liter; mm, millimeter; N.D., analyte not detected at method detection limit]

Property or constituent		U.S. Geological Survey station 04043140									
Sampling date		5/11/2005	7/27/2005	4/18/2006	7/25/2006	9/11/2006	4/23/2007	7/24/2007	9/11/2007	10/31/2007	4/23/2008
Record number		501155	501599	600151	601528	602665	700667	701612	702323	800005	800221
Metals											
Aluminum, fil	µg/L	16.6	7.9	29.2	16	6.6	34.4	8.9	6.7	23.3	84.7
Antimony, fil	µg/L	<.20	<.20	<.20	<.20	<.20	.06	E.03	E.03	<.14	<.14
Arsenic, fil	µg/L	.7	.9	.62	1	.72	.53	1.1	.86	.76	.41
Barium, fil	µg/L	11	15	11	14	16	9	16	15	12	7
Beryllium, fil	µg/L	<.06	<.06	<.06	<.06	<.06	<.06	<.06	<.06	E.01	.01
Cadmium, fil	µg/L	<.04	<.04	E.03	<.04	E.02	<.04	<.04	<.04	<.04	.08
Chromium, fil	µg/L	<.8	<.8	.19	.16	.23	.25	.19	.19	.28	.27
Cobalt, water, fil	µg/L	.068	.099	.087	E.03	.04	.04	E.02	E.04	.05	.05
Copper, water, fil	µg/L	.9	.7	4.8	4.1	4.2	1.5	E.31	E.27	E.98	1.6
Iron, fil	µg/L	142	82	113	73	57	98	42	74	170	112
Lead, water, fil	µg/L	E.05	<.08	.14	.21	.22	<.12	<.12	<.12	E.07	E.08
Manganese, fil	µg/L	22.1	18.1	12.3	9.1	12.9	9.4	7.9	12	19.3	5.7
Mercury, fil	µg/L	<.010	<.010	<.010	<.010	<.010	<.010	<.010	<.010	<.010	<.010
Molybdenum, fil	µg/L	E.3	E.3	E.2	E.3	E.3	.2	.3	.3	.2	E.1
Nickel, fil	µg/L	.57	1.57	1.3	.42	.3	.34	.1	.24	.32	.37
Selenium, fil	µg/L	<.4	<.4	E.07	.09	.09	.1	<.08	.09	.1	.08
Silver, fil	µg/L	<.2	<.2	<.2	<.2	<.2	<.1	<.1	<.1	<.1	<.1
Zinc, fil	µg/L	E.6	E.5	2.6	3.8	2.3	1.2	E.50	1.2	E1.7	2.1
Uranium (natural), fil	µg/L	.2	.4	.14	.23	.37	.07	.34	.29	.17	.05
Suspended sediment											
Suspended sediment, sieve diameter	Percent <0.063 mm	--	--	--	--	--	--	--	75	33	--
Suspended sediment concentration	mg/L	--	--	--	--	--	--	--	1	1	--
Cyanide	mg/L	E.0035	N.D.	N.D.	N.D.	N.D.	N.D. at 1600 E.0032 at 1610	N.D.	E.0024	N.D.	--

Appendix 1*G*. Physical properties and concentrations of major elements, solids, nutrients, metals, suspended solids, and cyanide, Dakota Creek at trail crossing near L'Anse, Baraga County, Michigan.—Continued

[ft³/s, cubic foot per second; E, estimated value; unfil, unfiltered; mg/L, milligrams per liter; µs/cm, microseimens per centimeter; °C, degrees Celsius; fil, filtered; $CaCO_3$, calcium carbonate; <, less than; --, no data; N, nitrogen; P, phosphorous; µg/L, micrograms per liter; mm, millimeter; N.D., analyte not detected at method detection limit]

Property or constituent		U.S. Geological Survey station 04043146									
Sampling date		**5/12/2005**	**7/28/2005**	**4/19/2006**	**7/26/2006**	**9/12/2006**	**4/24/2007**	**7/25/2007**	**9/12/2007**	**10/30/2007**	**4/24/2008**
Record number		**501158**	**501601**	**600152**	**601530**	**602667**	**700669**	**701615**	**702327**	**800003**	**800224**
Metals											
Aluminum, fil	µg/L	30.3	9.5	48.6	17.4	12.6	81	6.7	11.8	59.2	100
Antimony, fil	µg/L	<.20	<.20	<.20	<.20	<.20	.07	E.04	E.04	<.14	<.14
Arsenic, fil	µg/L	.4	.5	.35	.7	.36	.35	.46	.56	.42	.34
Barium, fil	µg/L	10	16	9	15	19	9	17	14	11	8
Beryllium, fil	µg/L	<.06	<.06	<.06	<.06	<.06	<.06	<.06	<.06	.01	.01
Cadmium, fil	µg/L	<.04	<.04	<.04	E.03	.06	<.04	<.04	<.04	<.04	E.02
Chromium, fil	µg/L	<.8	<.8	.26	.2	.12	.28	E.11	.17	.29	.29
Cobalt, water, fil	µg/L	.06	.081	.072	.05	.05	.05	.04	.05	.05	.05
Copper, water, fil	µg/L	1.4	.9	2.5	5.5	16.3	2.2	1.1	.83	1.4	1.8
Iron, fil	µg/L	286	287	182	416	140	152	121	304	271	129
Lead, water, fil	µg/L	.1	<.08	.09	.32	.41	E.11	<.12	<.12	E.06	E.08
Manganese, fil	µg/L	10.9	11.9	8.6	12.9	10.8	7.7	15.7	12.7	13.9	7.5
Mercury, fil	µg/L	<.010	<.010	<.010	<.010	<.010	<.010	<.010	<.010	<.010	
Molybdenum, fil	µg/L	<.4	<.4	<.4	<.4	<.4	E.1	.2	.2	E.1	<.2
Nickel, fil	µg/L	.39	.96	.87	.53	.82	.5	.3	.46	.43	.45
Selenium, fil	µg/L	<.4	<.4	E.07	.1	.09	.1	E.07	.1	.11	.1
Silver, fil	µg/L	<.2	<.2	<.2	<.2	<.2	<.1	<.1	<.1	<.1	<.1
Zinc, fil	µg/L	1	2.6	1.5	2.8	8.1	7.9	.98	.89	2.1	E1.7
Uranium (natural), fil	µg/L	.04	.06	.05	.05	.08	05	.05	.06	.06	.05
Suspended sediment											
Suspended sediment, sieve diameter	Percent <0.063 mm	--	--	--	--	--	--	--	19	67	--
Suspended sediment concentration	mg/L	--	--	--	--	--	--	--	7	1	--
Cyanide	mg/L	N.D.	N.D.	N.D.	N.D.	N.D.	E.0024	N.D.	N.D.	N.D.	--

Appendix 1*H*. Physical properties and concentrations of major elements, solids, nutrients, metals, suspended solids, and cyanide, Silver River near L'Anse, Baraga County, Michigan.—Continued

[ft^3/s, cubic foot per second; E, estimated value; unfil, unfiltered; mg/L, milligrams per liter; µs/cm, microseimens per centimeter; °C, degrees Celsius; fil, filtered; $CaCO_3$, calcium carbonate; <, less than; --, no data; N, nitrogen; P, phosphorous; µg/L, micrograms per liter; mm, millimeter; N.D., analyte not detected at method detection limit]

Property or constituent		U.S. Geological Survey station 04043150									
Sampling date		**5/11/2005**	**7/28/2005**	**4/19/2006**	**7/26/2006**	**9/13/2006**	**4/25/2007**	**7/26/2007**	**9/12/2007**	**10/30/2007**	**4/24/2008**
Record number		**501154**	**501602**	**600153**	**601532**	**602669**	**700671**	**701616**	**702326**	**800001**	**800222**
		Metals									
Aluminum, fil	µg/L	32.7	7.8	72.1	12.6	4.5	87.2	3.7	5.4	69	105
Antimony, fil	µg/L	<.20	<.20	<.20	<.20	<.20	.11	E.05	E.05	<.14	<.14
Arsenic, fil	µg/L	.5	.8	.38	.77	.62	.41	.9	.74	.54	.36
Barium, fil	µg/L	12	18	8	16	20	8	24	18	10	5
Beryllium, fil	µg/L	E.05	<.06	<.06	<.06	<.06	<.06	<.06	<.06	.01	.01
Cadmium, fil	µg/L	E.02	<.04	E.02	<.04	E.02	.04	<.04	<.04	.04	.33
Chromium, fil	µg/L	E.4	<.8	.22	.13	.12	.24	E.11	.14	.28	.27
Cobalt, water, fil	µg/L	.068	.082	.064	.04	.04	.06	.05	.05	.06	.06
Copper, water, fil	µg/L	1	.6	3.1	.75	2	5.2	.69	.48	1.4	1.3
Iron, fil	µg/L	140	98	122	126	97	120	85	144	240	129
Lead, water, fil	µg/L	E.05	<.08	.11	<.08	.13	.44	<.12	<.12	.16	.1
Manganese, fil	µg/L	10.3	7.6	9.9	12.2	8.2	7.5	28.2	11	14.7	5.8
Mercury, fil	µg/L	<.010	<.010	<.010	<.010	<.010	<.010	<.010	<.010	<.010	
Molybdenum, fil	µg/L	E.2	E.4	<.4	E.3	E.3	.1	.4	.3	E.1	<.2
Nickel, fil	µg/L	.52	1.15	.81	.27	.43	.5	.23	.36	.49	.36
Selenium, fil	µg/L	<.4	<.4	E.06	.08	E.06	.09	E.07	.09	.1	.08
Silver, fil	µg/L	<.2	<.2	<.2	<.2	<.2	<.1	<.1	<.1	<.1	<.1
Zinc, fil	µg/L	.8	.7	2.1	1.6	2.6	15.1	.89	1.7	2.6	2
Uranium (natural), fil	µg/L	.06	.15	.05	.1	.18	.07	.15	.15	.06	.03
		Suspended sediment									
Suspended sediment, sieve diameter	Percent <0.063 mm	--	--	--	--	--	--	--	50	33	--
Suspended sediment concentration	mg/L	--	--	--	--	--	--	--	1	1	--
Cyanide	mg/L	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	--

Appendix 3*A*. Results of macroinvertebrate sampling, Silver River upstream of East Branch near L'Anse, Baraga County, Michigan.

U.S. Geological Survey station 04043126	
Taxa	Quantity of individuals
ARTHROPODA	
Insecta	
Ephemeroptera (mayflies)	
Baetidae	2
Ephemerellidae	45
Heptageniidae	33
Leptophlebiidae	97
Odonata	
Anisoptera (dragonflies)	
Aeshnidae	3
Cordulegastridae	1
Zygoptera (damselflies)	
Calopterygidae	6
Plecoptera (stoneflies)	
Perlodidae	32
Pteronarcyidae	4
Megaloptera	
Corydalidae (dobson flies)	5
Trichoptera (caddisflies)	
Brachycentridae	13
Hydropsychidae	51
Limnephilidae	3
Molannidae	1
Philopotamidae	22
Coleoptera (beetles)	
Dytiscidae (total)	4
Elmidae	25
Diptera (flies)	
Athericidae	5
Chironomidae	20
Simuliidae	7
Tipulidae	7
TOTAL INDIVIDUALS	391

Appendix 3*A*. Results of macroinvertebrate sampling, Silver River upstream of East Branch near L'Anse, Baraga County, Michigan.—Continued

U.S. Geological Survey station 04043126		
Metric	Value	Score
TOTAL NUMBER OF TAXA	22	0
NUMBER OF MAYFLY TAXA	4	0
NUMBER OF CADDISFLY TAXA	5	0
NUMBER OF STONEFLY TAXA	2	1
PERCENT MAYFLY COMPOSITION	45.27	1
PERCENT CADDISFLY COMPOSITION	23.02	0
PERCENT DOMINANT TAXON	24.81	0
PERCENT ISOPOD, SNAIL, LEECH	1.28	1
PERCENT SURFACE AIR BREATHERS	1.02	1
TOTAL SCORE		4

Appendix 3*C*. Results of macroinvertebrate sampling, upper Gomanche Creek at Indian Road near Herman, Baraga County, Michigan.

U.S. Geological Survey station 04043135	
Taxa	Quantity of individuals
ANNELIDA (segmented worms)	
Hirudinea (leeches)	2
ARTHROPODA	
Crustacea	
Isopoda (sowbugs)	1
Insecta	
Ephemeroptera (mayflies)	
Baetidae	18
Caenidae	
Ephemerellidae	12
Heptageniidae	15
Leptophlebiidae	51
Odonata	
Anisoptera (dragonflies)	
Aeshnidae	1
Cordulegastridae	14
Plecoptera (stoneflies)	
Capniidae	7
Leuctridae	41
Hemiptera (true bugs)	
Gerridae	2
Megaloptera	
Corydalidae (dobson flies)	
Sialidae (alder flies)	6
Trichoptera (caddisflies)	
Hydropsychidae	8
Leptoceridae	6
Limnephilidae	6
Philopotamidae	10
Polycentropodidae	45
Coleoptera (beetles)	
Elmidae	4
Diptera (flies)	
Athericidae	1
Ceratopogonidae	17
Chironomidae	30
Simuliidae	4
Tabanidae	1
Tipulidae	13
TOTAL INDIVIDUALS	315

Appendix 3*C*. Results of macroinvertebrate sampling, upper Gomanche Creek at Indian Road near Herman, Baraga County, Michigan.—Continued

U.S. Geological Survey station 04043135		
Metric	Value	Score
TOTAL NUMBER OF TAXA	24	1
NUMBER OF MAYFLY TAXA	4	1
NUMBER OF CADDISFLY TAXA	5	0
NUMBER OF STONEFLY TAXA	2	1
PERCENT MAYFLY COMPOSITION	30.48	1
PERCENT CADDISFLY COMPOSITION	23.81	0
PERCENT DOMINANT TAXON	16.19	1
PERCENT ISOPOD, SNAIL, LEECH	.95	1
PERCENT SURFACE AIR BREATHERS	.63	1
TOTAL SCORE		7

Appendix 3*E*. Results of macroinvertebrate sampling, West Branch Tributary to Gomanche Creek near Herman, Baraga County, Michigan.

U.S. Geological Survey station 04043138	
Taxa	Quantity of individuals
ANNELIDA (segmented worms)	
Oligochaeta (worms)	2
ARTHROPODA	
Insecta	
Ephemeroptera (mayflies)	
Baetidae	13
Ephemerellidae	82
Leptophlebiidae	31
Odonata	
Anisoptera (dragonflies)	
Cordulegastridae	2
Plecoptera (stoneflies)	
Perlodidae	15
Hemiptera (true bugs)	
Gerridae	1
Megaloptera	
Corydalidae (dobson flies)	1
Trichoptera (caddisflies)	
Glossosomatidae	6
Hydropsychidae	23
Limnephilidae	26
Molannidae	2
Philopotamidae	8
Coleoptera (beetles)	
Chrysomelidae (adults)	2
Diptera (flies)	
Athericidae	5
Ceratopogonidae	1
Chironomidae	84
Tipulidae	7
MOLLUSCA	
Pelecypoda (bivalves)	
Unionidae (mussels)	2
TOTAL INDIVIDUALS	314

Appendix 3*E*. Results of macroinvertebrate sampling, West Branch Tributary to Gomanche Creek near Herman, Baraga County, Michigan. —Continued

U.S. Geological Survey station 04043138		
Metric	Value	Score
TOTAL NUMBER OF TAXA	20	1
NUMBER OF MAYFLY TAXA	3	1
NUMBER OF CADDISFLY TAXA	5	0
NUMBER OF STONEFLY TAXA	1	1
PERCENT MAYFLY COMPOSITION	40.13	1
PERCENT CADDISFLY COMPOSITION	20.70	0
PERCENT DOMINANT TAXON	26.75	0
PERCENT ISOPOD, SNAIL, LEECH	.32	1
PERCENT SURFACE AIR BREATHERS	.96	1
TOTAL SCORE		6

Appendix 3G. Results of macroinvertebrate sampling, Dakota Creek at trail crossing near L'Anse, Baraga County, Michigan.

U.S. Geological Survey station 04043146	
Taxa	Quantity of individuals
ANNELIDA (segmented worms)	
Hirudinea (leeches)	2
Oligochaeta (worms)	2
ARTHROPODA	
Insecta	
Ephemeroptera (mayflies)	
Baetidae	3
Ephemerellidae	9
Heptageniidae	32
Leptophlebiidae	51
Odonata	
Anisoptera (dragonflies)	
Cordulegastridae	4
Gomphidae	2
Plecoptera (stoneflies)	
Peltoperlidae	23
Perlidae	13
Pteronarcyidae	1
Hemiptera (true bugs)	
Gerridae	1
Megaloptera	
Corydalidae (dobson flies)	8
Sialidae (alder flies)	3
Trichoptera (caddisflies)	
Hydropsychidae	31
Lepidostomatidae	1
Limnephilidae	6
Philopotamidae	44
Coleoptera (beetles)	
Elmidae	13
Diptera (flies)	
Athericidae	19
Ceratopogonidae	5
Chironomidae	24
Simuliidae	3
Tipulidae	21
MOLLUSCA	
Pelecypoda (bivalves)	
Unionidae (mussels)	1
TOTAL INDIVIDUALS	324

Appendix 3G. Results of macroinvertebrate sampling, Dakota Creek at trail crossing near L'Anse, Baraga County, Michigan.—Continued

U.S. Geological Survey station 04043146		
Metric	Value	Score
TOTAL NUMBER OF TAXA	26	1
NUMBER OF MAYFLY TAXA	4	1
NUMBER OF CADDISFLY TAXA	4	0
NUMBER OF STONEFLY TAXA	3	1
PERCENT MAYFLY COMPOSITION	29.32	1
PERCENT CADDISFLY COMPOSITION	25.31	0
PERCENT DOMINANT TAXON	15.74	1
PERCENT ISOPOD, SNAIL, LEECH	1.23	1
PERCENT SURFACE AIR BREATHERS	.31	1
TOTAL SCORE		7

Keweenaw Bay Indian Community

Surface Water Organics Monitoring Program
Final Report: Oct, 2003-Sept, 2004

Prepared by:
Marc K. Slis, KBIC Water Quality Specialist
December 16, 2004

Grant Number: X396518301

Tribal Grant Manager/Contact: Marc Slis (6/30/03 to 09/30/04)

Water Resources Technician: Micah Petoskey (10/16/00 to 09/30/04)

I. Project Milestones Accomplished

A. Q1.
- Lower Falls River Watershed physically assessed for forestry management practices.

B. Q2.
- Submitted draft QAPP to US EPA

C. Q3.
- Submitted draft QAPP to US EPA
- QAPP approved by US EPA
- Received herbicide spraying plan from Mead Westvaco, modified QAPP sampling plan to match.
- Submitted amended QAPP to US EPA.
- Began baseline sampling of selected Surface Water Monitoring sites.

D. Q4.
- Mead Westvaco Submitted 2004 herbicide spraying plans to KBIC
- Baseline sampling was completed.
- Herbicide spraying was completed within and adjacent to the L'Anse Indian Reservation with KBIC water program staff present to monitor application at all sites.
- KBIC water program staff completed sampling at selected sites adjacent to sprayed sites. Results for all samples tested were "No Detect", per EPA 8151 methodology and detect limits

II. Objectives Update

Surface Water Herbicide Sampling/Data Analysis:

A. Q1.
This is the first quarter of the grant. Sampling is to begin the first month of herbicide spraying, dependent on the spraying plans of the logging companies actively managing properties within reservation boundaries.

B. Q2.
Marc contacted Mead Westvaco, the largest forestry concern operating within the reservation. They have agreed to submit their forestry management plan for 2004 to KBIC Natural Resources Department, including the 2004 spraying plan. The Surface Water Organics monitoring will closely follow this spraying plan, in order to better assess the impact of herbicide applications on reservation waters.

C. Q3.
Mead Westvaco submitted their forestry management plan. The sampling scheme was modified to accommodate the known herbicide applications for 2004. Baseline monitoring began with the June sampling month.

D. Q4.

Mead Westvaco completed the herbicide spraying projects noted in their forestry management plan. KBIC water program staff monitored the spraying applications and subsequently sampled the adjacent water bodies, soon after spraying was completed. All samples sent to the contract lab for analysis were found to be "No Detect", after being tested using EPA 8151 methods. Exceptions to this were two samples/bottles that were found to be broken in the process of shipping.

Reservation Pesticide/Herbicide Use Research:

A. Q1

A portion of the historical records available from past correspondence with BIA Forestry and local logging concerns was reviewed to develop a general picture of past spraying practices and the products used.

The Lower Falls River Watershed was physically assessed as part of a BIA Water Resources grant. This assessment was also used as an opportunity to assess the extent of past and present forestry practices in the watershed and their impact on surface waters within the reservation.

B. Q2.

Marc contacted the new BIA Forester for historical herbicide applications within the reservation. KBIC began to organize KBIC historical herbicide notices for entry into GIS.

C. Q3.

Historical herbicide spraying within the KBIC Reservation has been organized and is ready for entry into a GIS database upon receipt of any additional information from BIA, or Mead Westvaco. Some discussion has taken place concerning data format, database entries, associated data tables, or metadata. In addition, GIS analysis and display were also discussed. KBIC Water Quality Specialist attended an introductory GIS course.

D. Q4.

The KBIC GIS pesticide database/layer is still being finalized. Historical data is sparse and inconsistent. Some data has been entered. The final version will be a single layer that can be overlain with other water quality data layers, including water chemistry and flow data, to better characterize Reservation water resources and the impacts upon them.

III. Ongoing Activities

A. Q1.

Marc contacted the Tribal Pesticide Programs Council to inquire about background information, references and training.

B. Q2.

The Tribal Pesticide Programs Council has requested Marc Slis apply for membership in the council.

C. Q3.

Marc has requested to join the Tribal Pesticide Programs Council, in response to the Council's request for membership.

D. Q4.

Marc has joined the Tribal Pesticide Programs Council, in response to the Council's request for membership.

V. Grant Funds Drawn

Funds totaling $4,160.00 were drawn on this account. All funds were drawn as Line 53850 for sample analysis by a contract laboratory.

VI. Obstacles Encountered

A. Q1.
No obstacles were encountered.
B. Q2.
BIA Forester does not have historical herbicide application data.
C. Q3.
BIA Forester is still searching for historical herbicide application data.

Known herbicide spraying data is sparse and inconsistent in content.

Mead Westvaco spraying plan for 2004 is very limited, with some sites just off reservation boundaries. This has been addressed in the proposed sampling scheme within the QAPP amendment.
D. Q4.
BIA Forester is still searching for historical herbicide application data.

Known herbicide spraying data is sparse and inconsistent in content.

Mead Westvaco spraying was accomplished, but weather and communication over the weekend made sampling effectively, very difficult.

Several sample bottles were broken during UPS shipment to the contract laboratory.

VII. Summary of Work

Baseline sampling was performed according to the EPA approved QAPP methodology, on selected Reservation water bodies at sites coincident with preplanned, 20004 SWM sites. Herbicide applications of Oust at .75 ounces/acre and Accord at 1.5 quarts/acre occurred within or adjacent to the L'Anse Indian Reservation at three sites-plantations N101, N136 South and N149. All three sites were sprayed via helicopter release on September 09, 2004. KBIC Water Quality Specialist and/or KBIC Water Resources Technician were present at all three sites. BIA Forester, Jeff Kitchens was notified of the spraying, prior to application.

The helicopter/application crew consisted of one pilot and one ground crew for refueling and filling the herbicide tanks. Steve Nelson, Mead Westvaco was also present to monitor and coordinate the operations from the ground, via radio with the pilot and ground crew and to insure the public did not enter the area while spraying occurred.

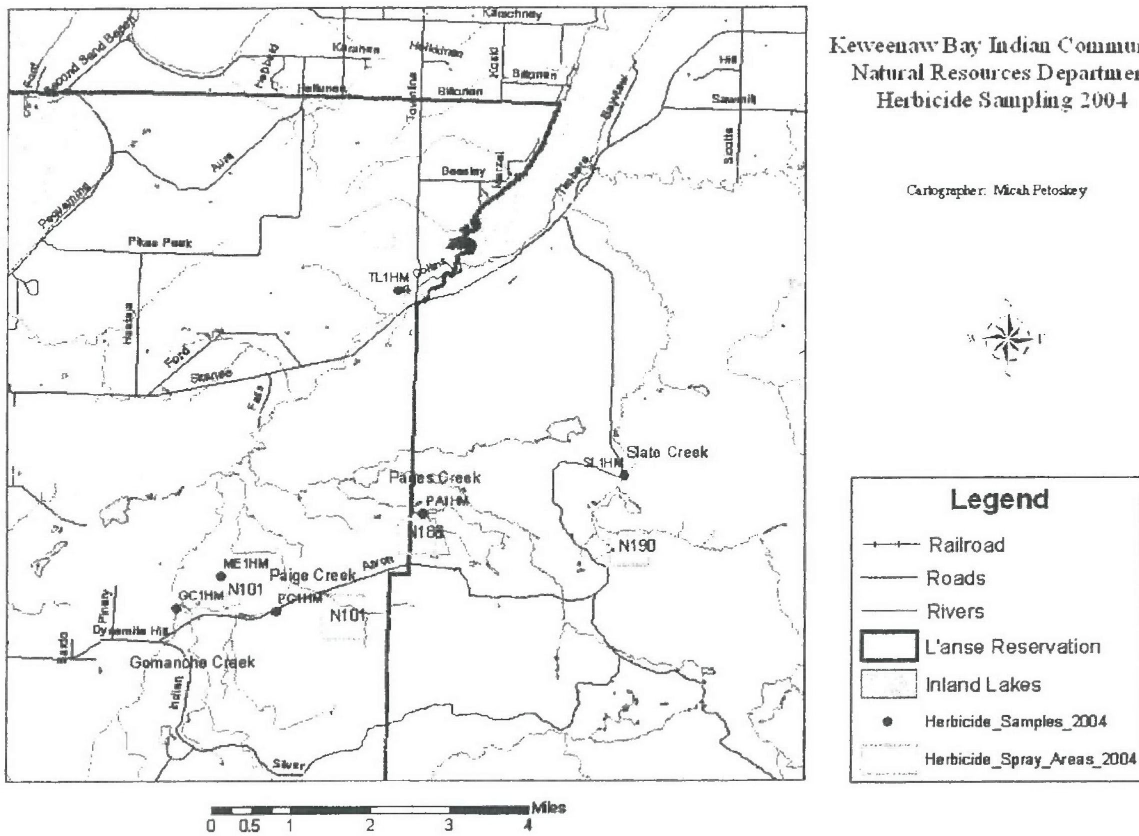
September 09 2004, spraying commenced at plantation N101. Winds were minimal. The spraying was accomplished by a helicopter with 18 ft boom sprayers extending both sides of the helicopter, which can be operated independently. Perimeter coverage was achieved with only a single boom active to insure accurate delivery with minimal, or no overspray. All application and safety regulations were followed at all times during the operation. Following competition of the site, the helicopter tanks and booms were rinsed with clean water loads, applied over an adjacent plantation. Ground operations and pesticide containers were accomplished within a portable containment system to insure no spillage to the environment at the refueling/landing site. Subsequent sites, N136 South and N149 were sprayed in exactly the same manner.

Monitoring/sampling performed according to the EPA approved QAPP methodology, occurred on September 15, 2004. Sampling coincided with the first precipitation event following application of the herbicides. The first rain event was chosen due to several factors including slope, vegetation and distance from the plantation sprayed to the closest water body, as well as the amount and accuracy of the application. After observing the applications, it was decided that a precipitation event would be necessary for transport of the herbicide to adjacent water bodies.

All monitoring sites were within 0.5 miles of the nearest point of plantations sprayed. In all cases, the area between the plantation and the monitoring site is heavily vegetated and wooded. Soils are mostly permeable sandy soils, covered with a thin layer of sandy/loamy soil, allowing the product to infiltrate the ground surface instead of run off. Taken together, these two factors would limit surface transport of the chemicals to adjacent water bodies. Slopes along the line of run off vary from 2% TO 20%, averaging 8 %, suggesting transport might occur in heavy run off which influenced the decision to monitor during or after the first heavy rain event following application. Raw data of the monitoring of each spraying site and GIS maps of application areas and monitoring points are included in the appendices.

Appendices

Appendix 1: Herbicide Application Areas and Monitoring Station Map



2004 Herbicide Site-Specific Sampling

Parameter	TL1HM	GC1HM	ME1HM	PG1HM	PA1HM	SL1HM
Date	9/15/2004	9/15/2004	9/15/2004	7/27/2004	7/27/2004	7/27/2004
2,4-D	SB	ND	ND	ND	ND	ND
2,4-DB	SB	ND	ND	ND	ND	ND
2,4,5-T	SB	ND	ND	ND	ND	ND
2,4,5-TP (Silvex)	SB	ND	ND	ND	ND	ND
Dalapon	SB	ND	ND	ND	ND	ND
Dicamba	SB	ND	ND	ND	ND	ND
Dichloroprop	SB	ND	ND	ND	ND	ND
Dinoseb	SB	ND	ND	ND	ND	ND
Picloram	SB	ND	ND	ND	ND	ND
Bentazon	SB	ND	ND	ND	ND	ND
MCPA	SB	ND	ND	ND	ND	ND
MCPP	SB	ND	ND	ND	ND	ND
Pentachlorophenol	SB	ND	ND	ND	ND	ND

SB = Sample Broken by Shipping Company

Appendix 3: Spraying Photos

Photo A: Townline Rd. plantation **Helicopter sprays at less than treetop level.**

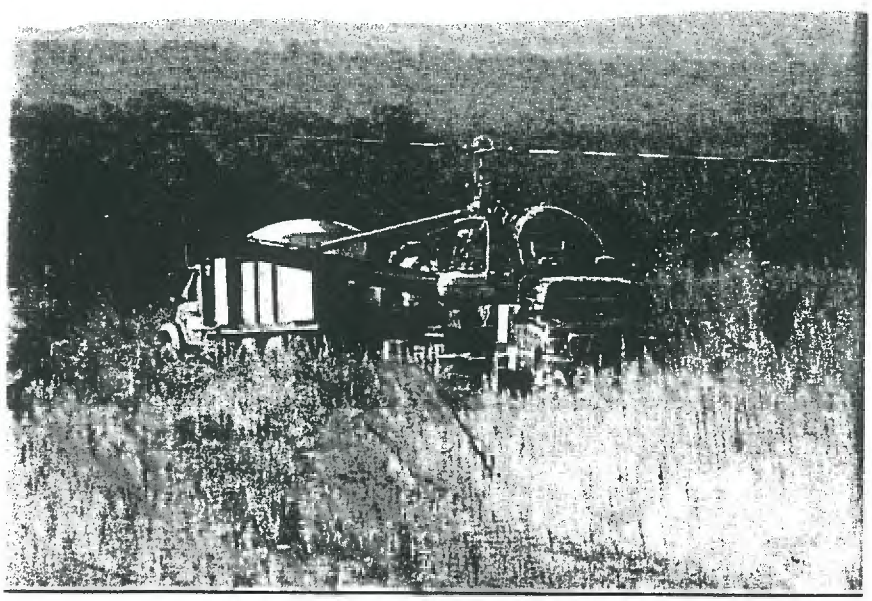


Photo B: Townline Rd. plantation **Helicopter refueling on landing pad/truck.**

Hydrologic Model of the Silver River Watershed
Baraga County, Michigan

Surface Water Modeling with HEC-HMS and HEC-RAS

AquaTerraTech

Melissa Trahan – Project Manager
Adam Ward – Project Manager
Shannon Culberson
Andrea Krevinghaus
Greg LeFevre

Submitted 15 April 2005
Michigan Technological University

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Introduction

The Surface Water Modeling Group (SWMG) of the Aqua Terra Tech (ATT) enterprise won a Haestad Methods, Inc. competition for the use of HEC-Pack services. The company provided software to model the surface water of the project area in addition to unlimited technical support. This surface hydrology model will be compared to the outputs of a Groundwater Modeling System (GMS) model as a full area calibration for the groundwater model.

SWMG will utilize the software and services from Haestad Methods to:

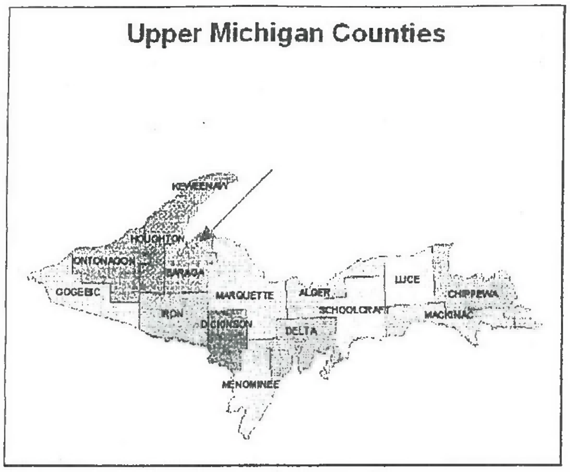
1. build and test a surface hydrology model (SHM) of the watershed
2. estimate river stages for the source/sink conditions in the existing GMS model
3. compare SHM results in ungaged streams to the estimated groundwater discharges to calibrate both models simultaneously

Hydrologic Engineering Center Hydrologic Modeling System (HEC-HMS) will be used to estimate flows in each subbasins, which contain ungaged tributaries of the Silver River. The HMS calculated discharges will be entered into the Hydrologic Engineering Center River Analysis System (HEC-RAS). This program will predict the river stage along main channels and aids in floodplain delineation. The results from the SHM will be compared to the estimated flows from the groundwater model to calibrate both models. These two models will provide tools for the Keweenaw Bay Indian Community (KBIC) to analyze the effects of future developments.

Background

ATT, a student group at Michigan Technological University (MTU), was started as an engineering consulting enterprise. It currently consists of undergraduate students studying civil, environmental, and geological engineering. MTU created the Enterprise Program to allow students a curriculum path for developing technical skills and business practices in a multidisciplinary project setting. Enterprise teams are managed by the student members, with a faculty member serving as the advisor.

The KBIC is located in Baraga County in Michigan's Upper Peninsula (Figures 1 and 2). The reservation was established by the Treaty of 1854 and encloses 70,327 acres (284600000 m^2) of land, including: 17 miles (27.36 km) of shoreline on Lake Superior, 80 miles (128.75 km) of streams and rivers, 15,000 acres (6070000 m^2) of lakes, and 3,000 acres (12140000 m^2) or wetlands. The KBIC is a sovereign nation established by the US Government in 1936. Having lived on the land for over 150 years, the members of the tribe are striving to better themselves and their standards of living through many means, including education, child care, universal health care for tribe members, care for the elderly, and employment opportunities.



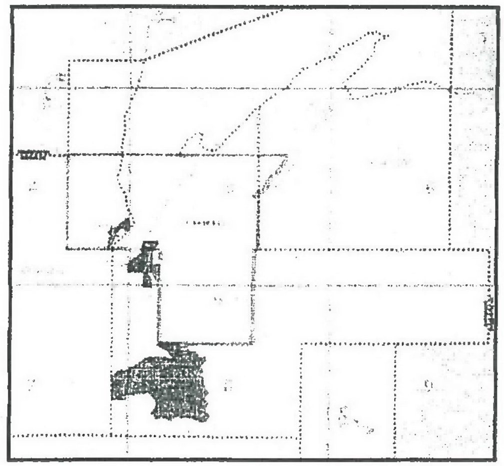


Figure 1: *The Silver River Watershed is located in Baraga, County Michigan. (left)*
Figure 2: *The majority of the basin lies in land owned by the Keweenaw Bay Indian Community. (right)*

The KBIC is rapidly developing and a growing percentage of its land is being used for construction of facilities. The KBIC has an interest in protecting the water resources on its land. Community planners must decide which land should be available for construction and what impacts the development could have on the hydrology of the watershed. A grant from the Environmental Protection Agency (EPA) was awarded to the KBIC and Dr. John Gierke to fund the project in 2000. The objectives of the project were:

1. to assess the hydrogeology within the Herman, Silver, and Zeba watersheds
2. to develop a water budget for the proposed study areas
3. to identify areas of groundwater recharge and discharge

To create an accurate groundwater model, members of ATT collected field-data from the Silver River watershed area using water level meters, seismographs, and Global Positioning System (GPS) Trimble units. These instruments were used to determine the depth to bedrock and groundwater table at various well locations. This data, along with river and stream locations and topographical data, were entered into the GMS groundwater model.

Dr. Gierke led the creation of the ATT enterprise as a means to achieve the objectives of the grant while involving undergraduate students in a professional experience. ATT has been working for 6 years to gather data from the watershed and construct a groundwater model using GMS and Geographic Information Systems (GIS) software programs. With the model nearing completion, it became necessary to calibrate the model, insuring a larger degree of accuracy was achieved.

Objectives and Scope

Objectives

The specific goal of creating the surface water model of the Silver River watershed was dual fold: to check the accuracy of the developing subsurface model of the region, and to provide a tool to the KBIC to assess the impacts of possible development on the watershed.

Scope

This model is a simplified representation of the actual watershed. Minimal field work was conducted to gather the information used in the simulation because the time frame of the project was during the winter, with snow and ice preventing data acquisition. Instead data were collected from established sources which can lead to generalized information. For example, there is no established precipitation gage within the boundaries of the watershed, and nearby sources were substituted. In addition, several components such as watershed slope and Soil Conservation Service (SCS) curve numbers were assumed to be uniform over the area of each sub-basin.

HEC-HMS and HEC-RAS are powerful tools that can design both relatively simple and complex models. The more simple methods chosen for use in these models tend to be more applicable for event based simulation rather than longer term modeling, where greater accuracy requires more complex methods.

Some characteristics of the watershed were estimated or neglected for the simulation. Baseflow to the stream was estimated from past information, and evapotranspiration and soil moisture accounting were neglected for the purposes of the model. Due to the low level of development on the watershed it was assumed that impermeable surfaces could be neglected, when in fact some do exist (roads, bedrock outcroppings, etc.).

Methods & Procedures

HEC-HMS Model

Basin Model

Topographic maps of the entire watershed were obtained from the Michigan DNR website, and the topographic divides were used to estimate seven sub-basins (Figure 3). GMS software's GIS capabilities allowed for accurate estimations of each respective sub-basin's area. Down stream connections and junctions were constructed, and reaches were placed where necessary to separate the sub-basins. USGS stream gage data was collected for the Silver River to serve as a check of total outflow from the watershed.

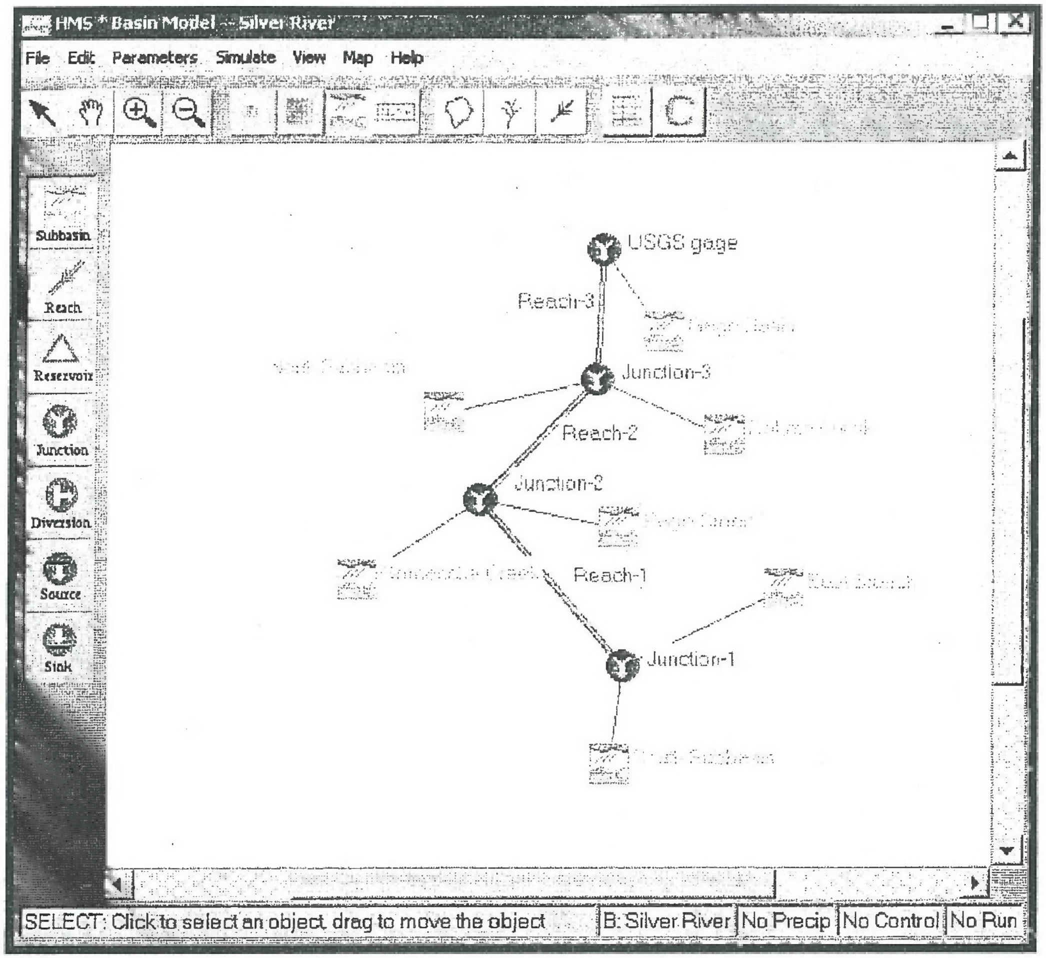


Figure 3: HEC HMS basin model of the Silver River watershed depicting the seven subbasins and three reaches.

The next step in the preparing the model was to decide which parameters would be used to simulate the sub-basin. Methods developed by the SCS were chosen to represent this model in the majority of cases. The components imported into the basin model are as follows:

a) *Loss Model / Infiltration:*
The SCS Curve Method was chosen to determine loss rate. The vast majority of the watershed is wooded, with some variability of cover due to occasional logging or clearing, etc. and a curve number of 58 was chosen to represent the watershed. This value was based not only on the land use, but also the soil type. Based upon a soil report of the area and field experiences, the group chose a type "B" Hydrologic Soil Group (approximately Sandy Loam).

b) *Transform:*
A simple SCS lag time was utilized to determine a synthetic unit hydrograph for the model's transform demands. The lag time is the basis for finding the time of concentration, and is dependant upon the length to the divide, average watershed

slope, and SCS curve number. The length of stream and the average slope were found using the digital representation of the watershed from GMS, as previously stated.

$$t_p = \frac{l^{.8} \cdot \left(\frac{1000}{Cn} - 10 + 1 \right)^{.7}}{1900 y^{.5}}$$

c) *Baseflow:*
The baseflow contribution to the watershed was represented using the constant monthly option. Discharge data from two years of the USGS gauging station on the Silver River were analyzed on a monthly basis to estimate total baseflow at the final discharge point. The contributing component from each subbasin was determined using the total length of perennial stream in the respective subbasins, and each subbasin's land area. Both the fractional area and fractional stream lengths were averaged to determine what percentage each sub-basin contributed to total baseflow.

d) *Reaches*:
The Muskingum Cunge Standard method was used to simulate the reaches in the model. Archived data from several river walk observations were used in determining general characteristics of the channel. The channel was modeled as a prism. The reach length and energy slope were found using topographic maps. The bottom diameter and side slope of the steam were determined from the field walks. Manning n values were determined with standard tables, with the model representing a typical upper Great Lakes region river.

Meteorological Model

Precipitation data was obtained from Herman Weather Station in Herman, MI approximately 1.5 miles (2.41 km) southwest of the watershed. Precipitation was considered constant over the entire watershed. Due to the lack of other stations, relative closeness of Herman, and lack of weather affecting topography, no attempts were made to distribute rainfall. Daily incremental data were entered into a simulated rain gage, which was applied to each sub-basin. Precipitation data for the entire time period were entered for modeling.

Control Specifications

Control specifications for the model were designed to encompass the full time period for which discharge data were available from the USGS gauging station. This provided ease in comparison, and allowed easy determination if the model were accurate over a long period. The dates for the control specification were set from 10/01/99 to 9/30/2003, with a time interval of twenty four hours.

HEC-RAS Model

The HEC-RAS model was constructed to determine surface water elevations, floodplains, and to calibrate the GMS model. Cross-sections of the rivers were estimated to be trapezoidal, with information on width and depth from data collected during past river observation walks for approximately 10% of the river length modeled. River characteristics were estimated in areas for which no information was available. Over-bank topography was constructed based quadrangle maps at the river cross-section locations. Additional cross sections were created using an interpolation feature of the software.

Manning's n values were chosen from a table of standard values for natural channels. Information on the composition of the banks and river channel was collected from river observation walks and reasonable estimates were made where no data was available. Testing revealed that the value chosen did not have a significant impact on the model.

Flow data collected from the HEC-HMS model was utilized to provide control points in the model. Flow was assumed to be uniform and steady. The HEC-HMS model output was only for the discharge from each subbasin, meaning that flows needed to be estimated in the upper portions of each reach. Baseflow at the head of each river was assumed to be 5cfs (.142 m^3/s), a conservative estimate. This estimate means that the model will show slightly higher volumes of water in each reach, resulting in a degree of safety in floodplain estimation. Calculated monthly baseflow data is shown in Appendix A. Flows at intermediate locations were determined by linear interpolation of the discharge and estimated base flows.

Known water depths at the gauging station were used as a limit for the model. Other specified flow points were limited by normal depth, with slope being calculated as the change in river height divided by the length of river in the subbasin.

Results and Discussion

HEC-HMS Model

The HMS model was run for the time period per the control specifications. An output hydrograph of the model was produced at the simulated gauging station (Figure 4). The results from the two year simulation can be compared to the actual measured flow rate at the USGS gauging station on the Silver River (Figure 5).

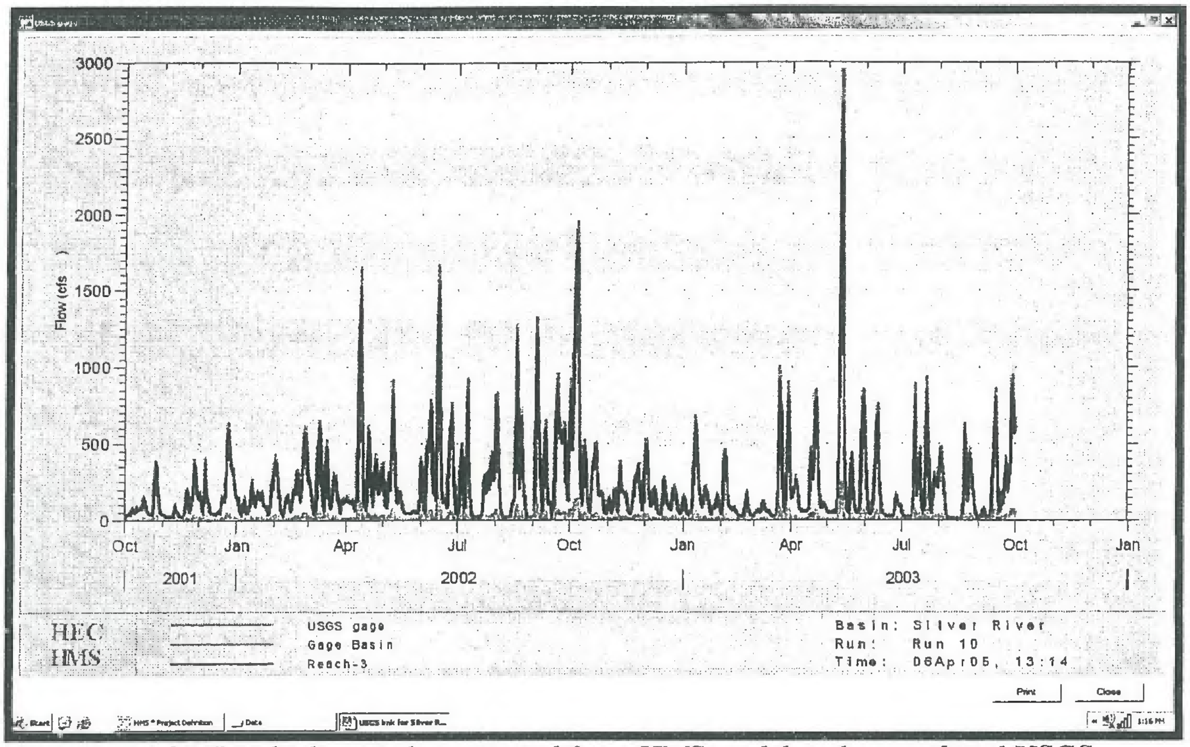


Figure 4: *Outflow hydrograph generated from HMS model at the simulated USGS gauging station.*

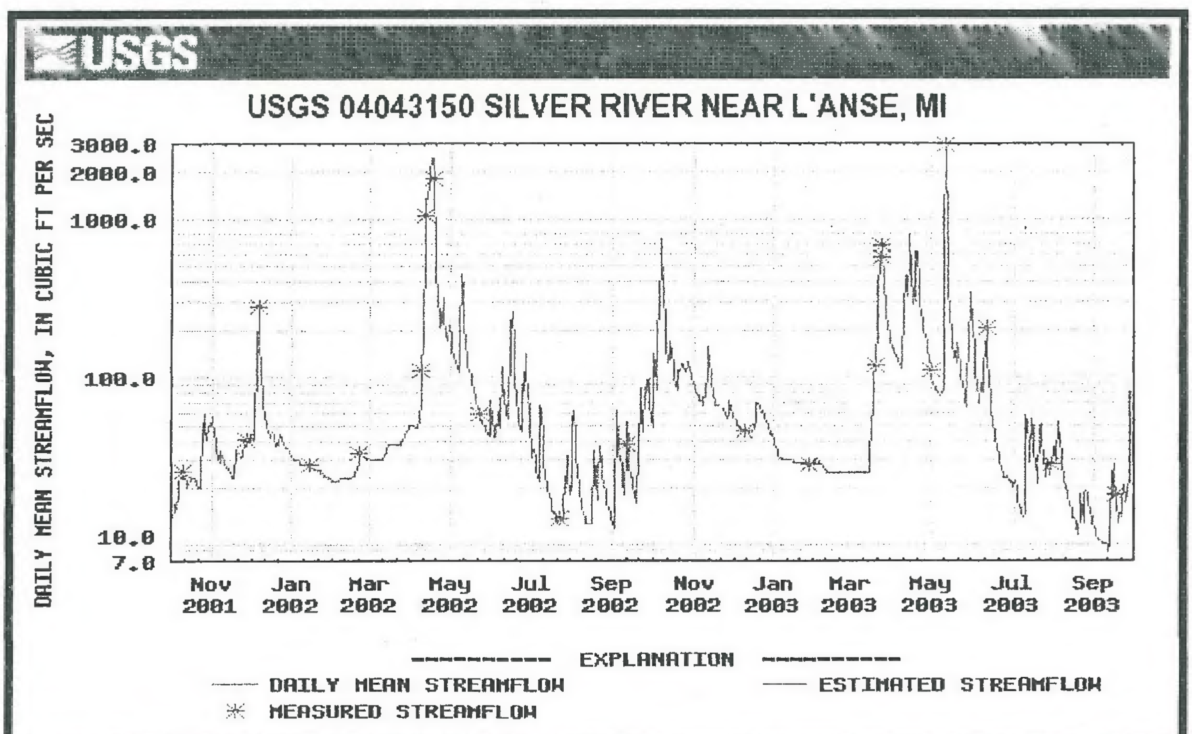


Figure 5: *Recorded data from the USGS gauging station on the Silver River.*

The outflow hydrographs indicate that the HMS model has a clear correlation with the measured data. The model shows a great variety of flow peaks, which are often between 500 cfs (14.16 m^3/s), and 1000 cfs (28.32 m^3/s),. These peaks do not commonly occur in the actual data. This is possibly due to the model being more sensitive to small precipitation events than the actual watershed due to neglecting evapotranspiration and soil moisture properties. The model seems to produce acceptable results of predicting when the peak discharges will occur, and the peak flowrates at those maximums are close to known values.

Table 1: *Comparison of recorded discharge and model predictions of annual peak flow rate.*

	Date of Peak		Peak Discharge (cfs)	
	USGS Measured	Model Predictions	USGS Measured	Model Predictions
2002	17-Apr-02	12-Apr-02	2,650	1655
2003	12-May-03	12-May-03	3,180	2951

The HMS model yields reasonable results. The observed tendency is for the model to over predict the impacts of small precipitation events, and underestimate the magnitude when flowrates are large (Figure 6). For nearly the entire duration of the control specifications, the model predicts greater discharge results than are actually encountered, except during the spring melt season peak.

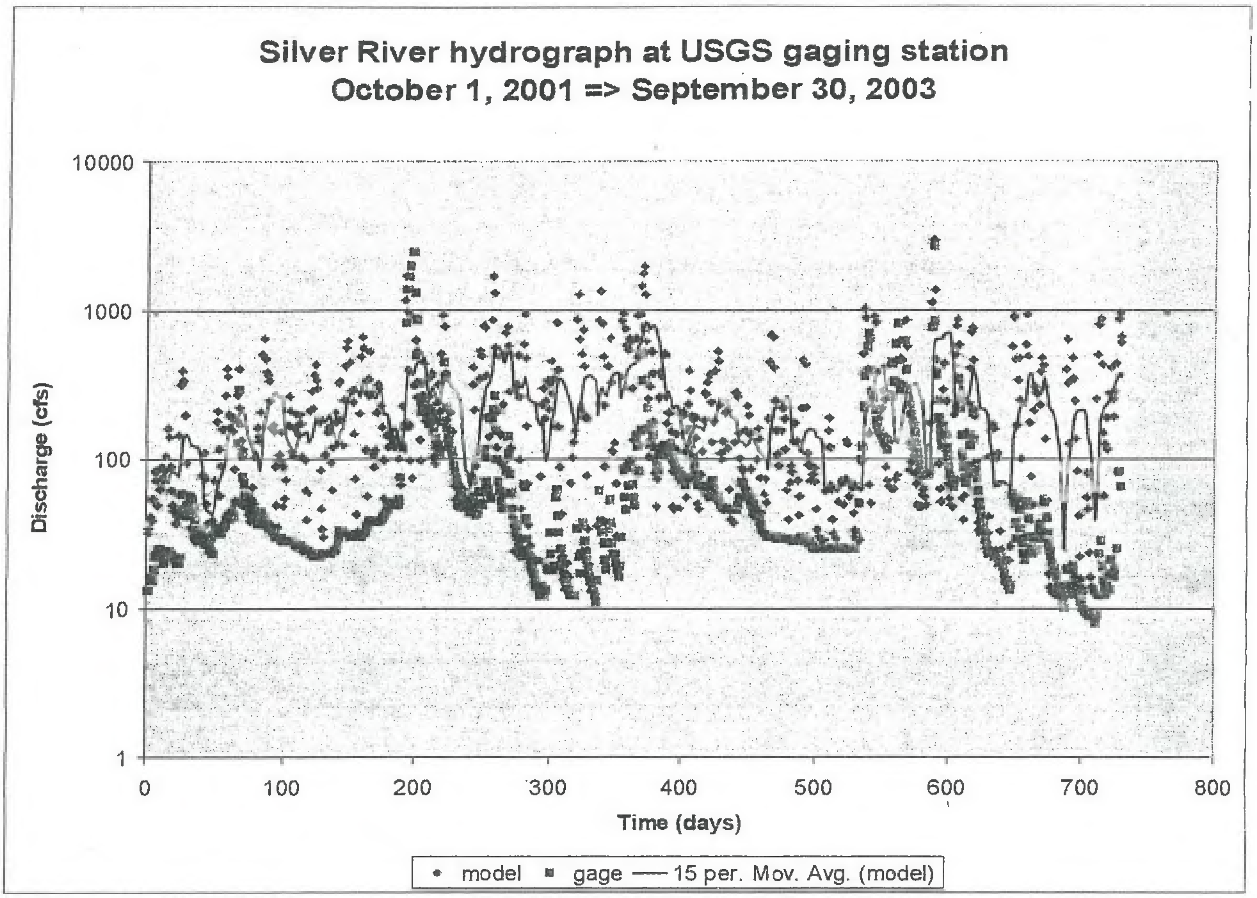


Figure 6: *Scatter plot of the daily average discharge data from both the actual USGS gauging station and the HMS simulated gauging station, along with the 15 day moving average of the model data.*

There are several possible explanations for this seasonal phenomenon. The comparison to the actual data is likely related to the climate of the region. The beginning of April is when the heavy snowfalls from the previous winter most commonly melt. Although this hydrological component is reflected in the increased baseflow for the month, a sudden increase in temperature combined with rain on frozen ground (which is not accounted for in determining the SCS curve number) can produce high flowrates quickly with little actual precipitation perceptible to the HMS model.

The model's increased reaction to common small precipitation events may be due to the simplicity inherent in the simulation. Although infiltration, lag time, etc. are accounted for in small ways, a more complex system exists in nature, with varied slopes and terrain, fast and slow water flow areas, evapotranspiration, vegetation interception, etc. Many natural forces in this relatively undeveloped watershed keep the system much more stable than what this simple model tends to predict.

HEC-RAS Model

The HEC-RAS model for the Silver River (Figure 7) was run with the peak flows predicted by the HMS model for 2002 and 2003 from delineated sub-basins. The program outputs predicted flow at points in the rivers sections including critical or subcritical flow and energy grade line. Data can be viewed as water surface profiles (Appendix B) or as an isometric view of rivers and water levels (Figure 8).

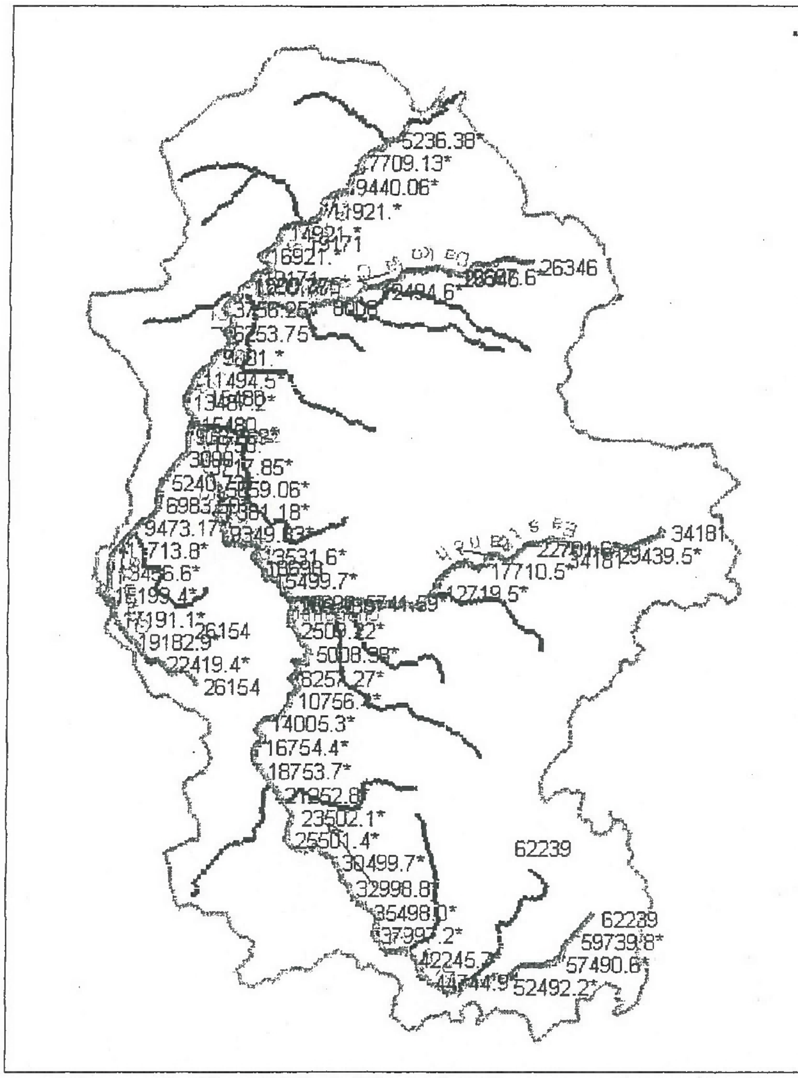


Figure 7: The HEC-RAS Model Geometry (plan view)

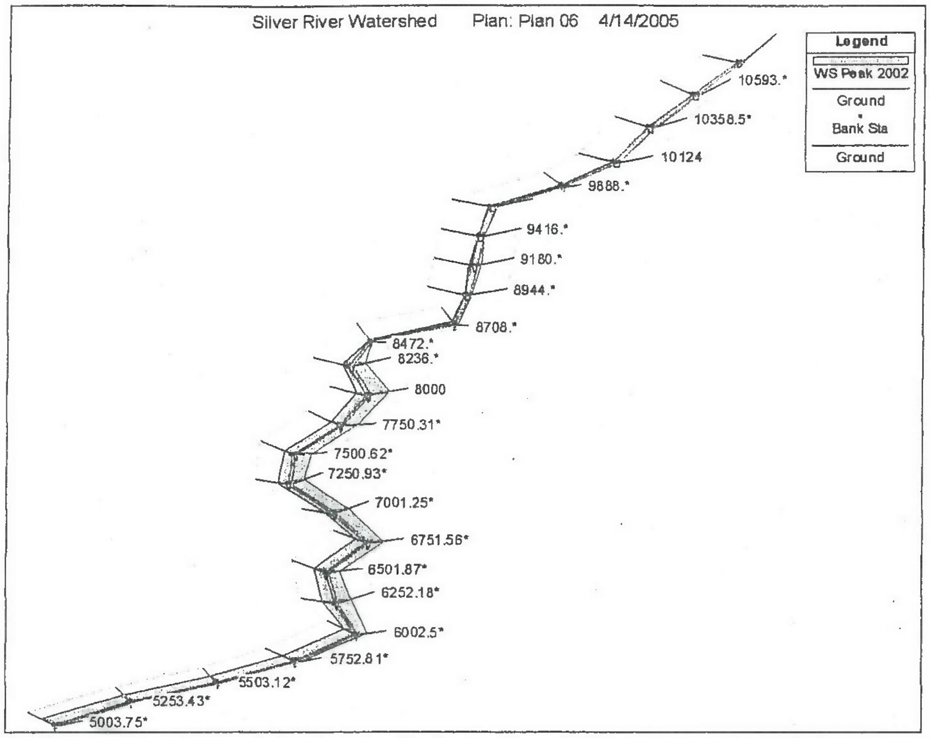


Figure 8: Isometric view of the lower Dakota Creek during predicted flooding in 2002.

Cross sections along the river can be viewed to show elevations at points along the river (Figure 9). The results of the analysis show that there was flooding during the peak flows of both 2002 and 2003. Floodplains were generally within 100 feet (30.48 m) of the river with the exception of a few points.

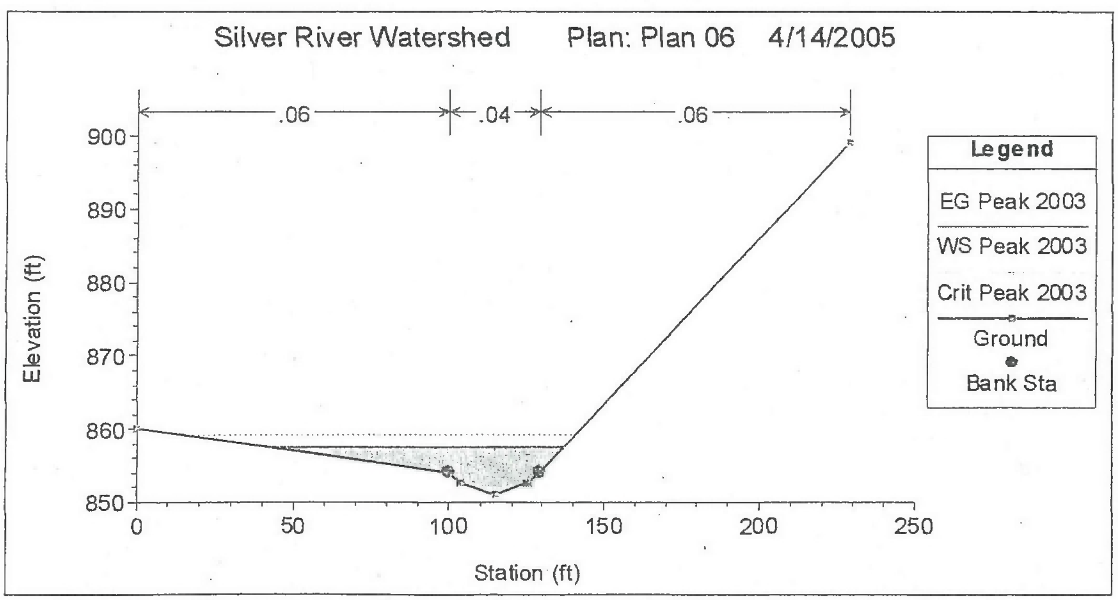


Figure 9: Cross section showing flooding in the Silver River near Arvon road.

There are several potential sources of error in the HEC-RAS model. Some flow data was obtained from the HMS model, which has its own sources of error. The remaining flow values were estimated using the team's engineering judgment. River-walk profiles from 2002 and 2003 were completed for only a small portion of the rivers modeled. The remaining cross sections were estimated from topographic maps and previous modeling experience. Manning's n values were assumed from a table of known values, but not checked in the field. Also, one value was applied to the entire channel which discounts the effect of changing channel conditions.

Comparison to Groundwater Model

The final flow results from the HMS model were compared to ATT's groundwater flow model for the Silver River region. The average flowrates for the duration of the control specifications were tabulated for (Table 2).

Table 2: *Comparison of flow results between the HMS and GMS models, as well as adjusted HMS results.*

Location	HEC Flow (cfd)	HEC adjusted (cfd)	GMS Flow (cfd)	Ratio	Ratio adjusted	% Difference between models
USGS Gage	20206995	7216784	8965381	2.25	80.5%	19.5%
Gomanche Creek	1376441	491586	658000	2.09	74.7%	25.3%
East Branch	4779341	1706908	1820106	2.63	93.8%	6.2%
South Subbasin	5777218	2063292	1040511	5.55	198.3%	98.3%
Junction 1	10556636	3770227	2860617	3.69	131.8%	31.8%
Junction 2	13865602	4952001	4394466	3.16	112.7%	12.7%
Junction 3	18800841	6714586	7963961	2.36	84.3%	15.7%

The output results from the HMS model are substantially higher than those derived from the groundwater flow water. The basis for comparison was the *average flows* for the two year period for each of the subbasins used in the study. As previously noted, the HMS model yielded consistently higher outputs than the stream gage for all but the peak conditions. The comparison to GMS reaffirms this observation, and was cause for further evaluation of the HMS model.

One of the major components of the hydrologic cycle that was neglected during the construction of the HMS model was evapotranspiration. In a heavily forested region, such as the Silver River watershed, this factor is significant.

A water budget of the region has been prepared (Appendix C). The evapotranspiration calculated from the water budget was subtracted from the flow results of the HMS model to obtain HEC adjusted flows. When the adjusted flow outputs of the HMS model were compared to the GMS model, the results become much closer to one another. When all subbasins and junctions are compared, the models average within thirty percent of one another. If the largest anomaly, the South Subbasin and its effects on Junction 1, are not included the models are within fifteen percent of one another.

This analysis illustrates the importance of all components of the model when constructing longer time scale simulations. Ignoring evapotranspiration had a dramatic impact on the results, which became exposed when the models were compared to both a known gauging station and an independent GMS model.

Conclusions

The HEC models have been completed to sufficiently meet the objective of calibration for the GMS model. Computed flows were within a reasonable range between the two models. The RAS model is working and can be utilized to roughly determine floodplains within the Silver River watershed.

Future Recommendations

Based on the performance of the model some recommendations for future exploration have been developed:

1. Modify the HMS model to include evapotranspiration. The GMS model can already utilize this data and provide a calibration tool.
2. Explore the flow irregularity in the South sub-basin. The area delineated is large and perhaps further dividing could help to minimize the inconsistency between the models.
3. Collect field data when weather is favorable. Field observations and data collection could be used to more accurately determine SCS curve numbers, Manning's n values, and evapotranspiration data. Measuring river cross sections would improve the accuracy of the RAS model.
4. Place a rain gage within the watershed to gather more accurate precipitation data.
5. Modify the models to account for the accumulation and melt of snowfall.
6. Develop a spreadsheet application to help KBIC planners more easily modify the models to test future scenarios.

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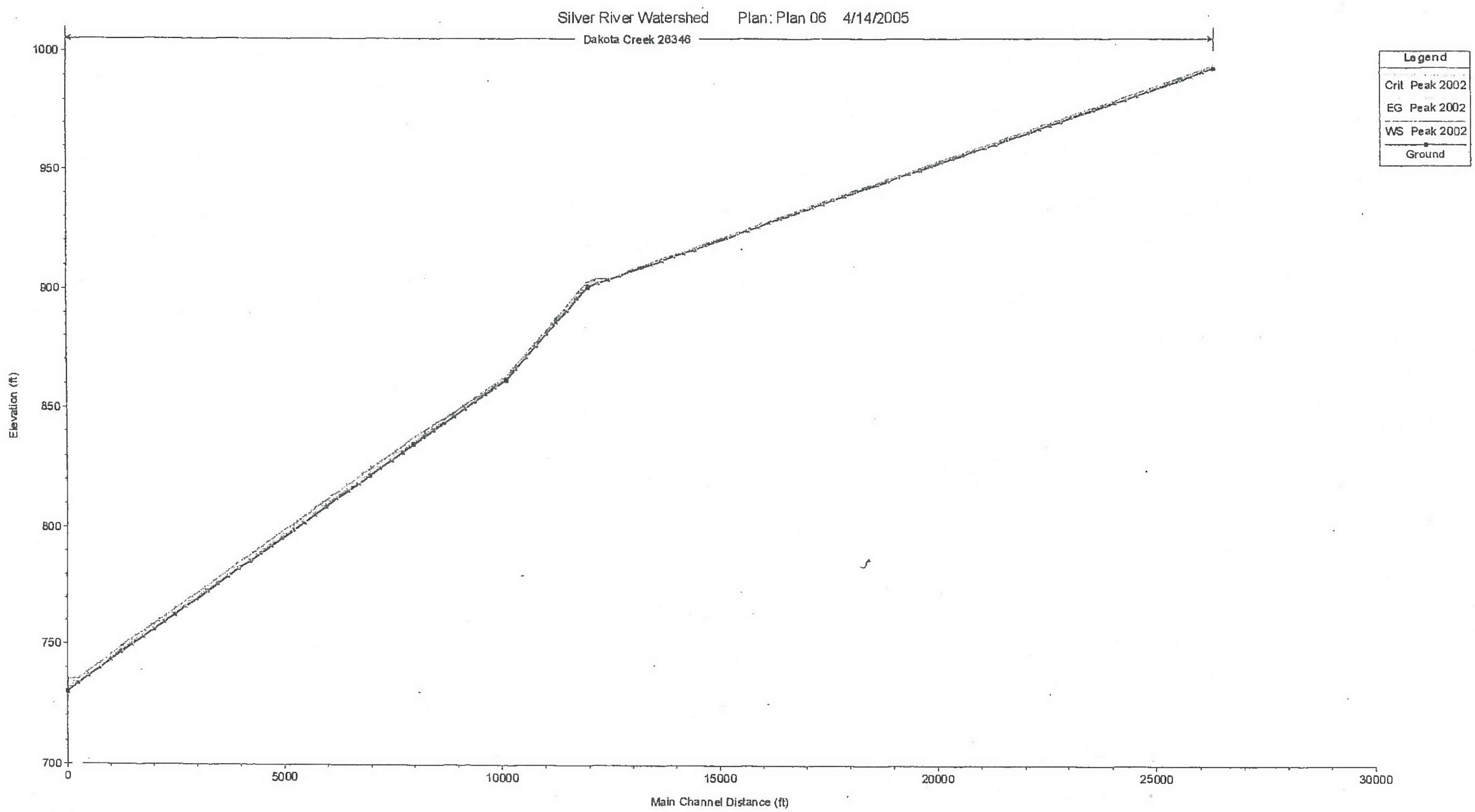
APPENDIX A – Baseflow Calculations

	Areas feet squared	Areas square miles	Total lineal footage of stream	percentage	estimated baseflow ft^3/d)	estimated baseflow (cfs)
Gage	126866989.1	4.55	NA	NA	649374	7.52
Dakota	278115098.4	9.98	63071	17.40	1423545	16.48
North	17072792.35	0.61	40066	11.05	87388	1.01
Page	176588600	6.33	37736	10.41	903877	10.46
East Branon	443235078.2	15.90	74404	20.52	2268719	26.26
Grum	122707637	4.40	36579	10.09	628085	7.27
South	530205627.3	19.02	110708	30.53	2713881	31.41
		sum	362564	total		100.4035703 percent

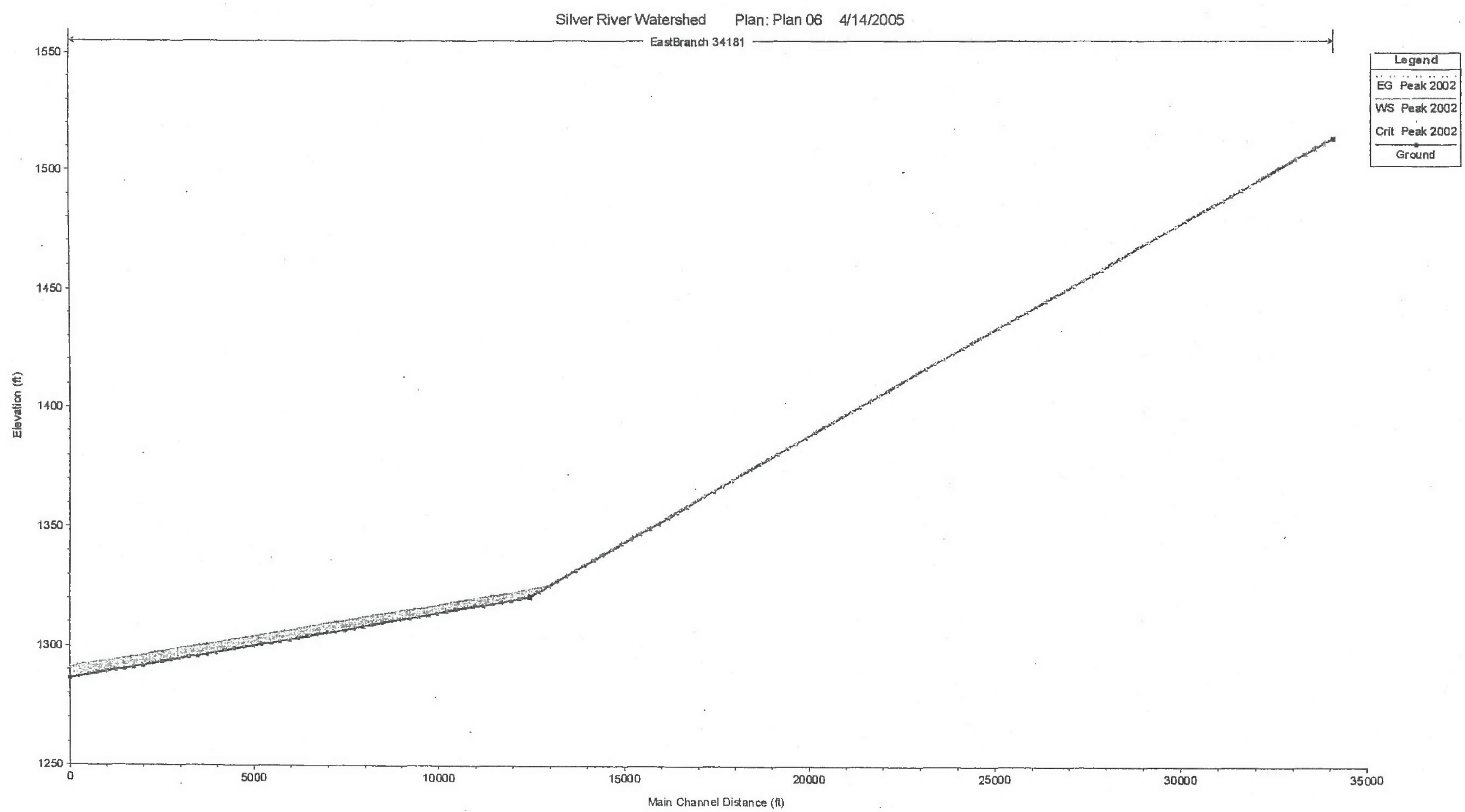
Recharge (USGS) (ft/d): 0.005118545 ave. for WY2002, based on area

APPENDIX B – Water Surface Profiles (2002 Peak flow)

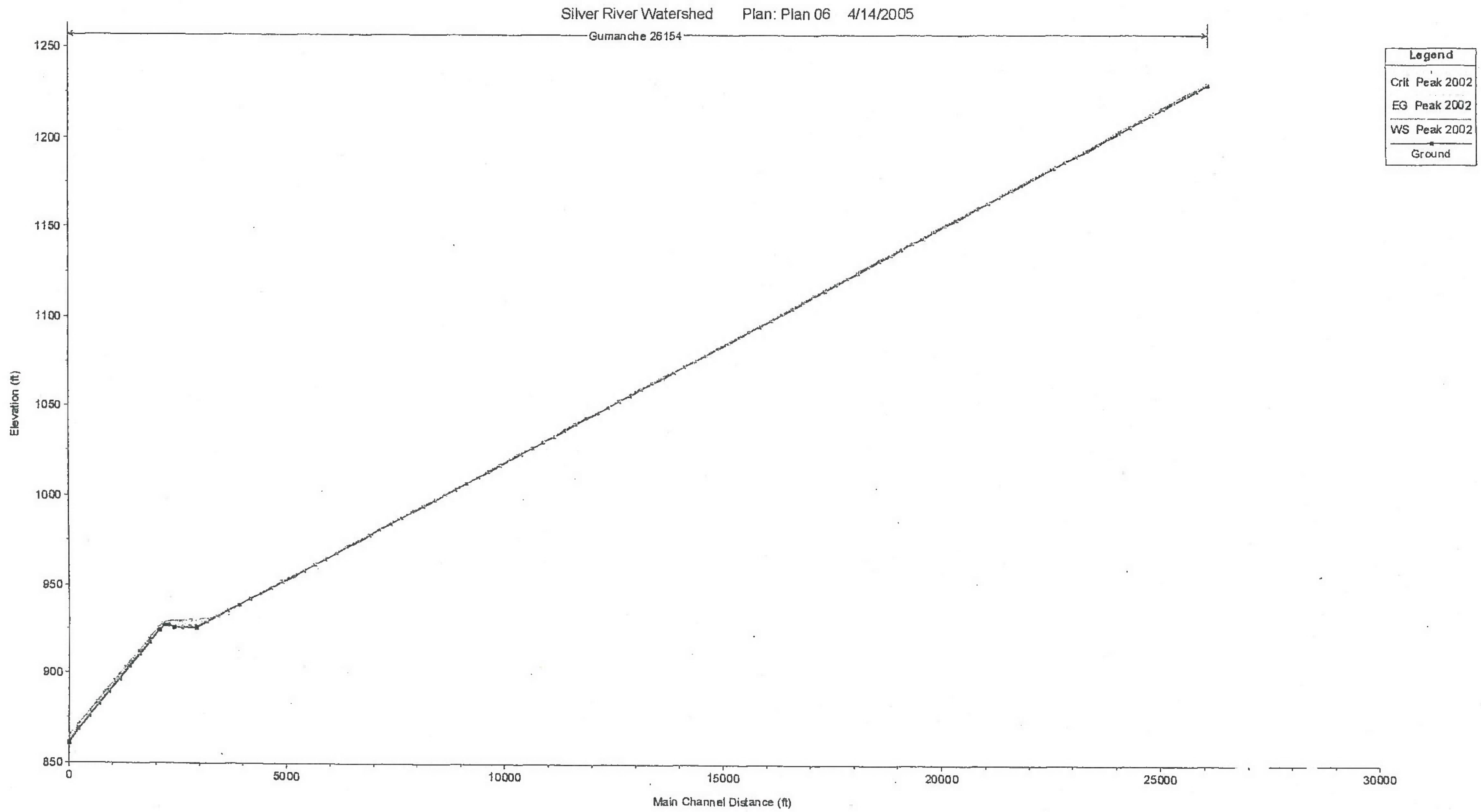
Dakota Creek



East Branch

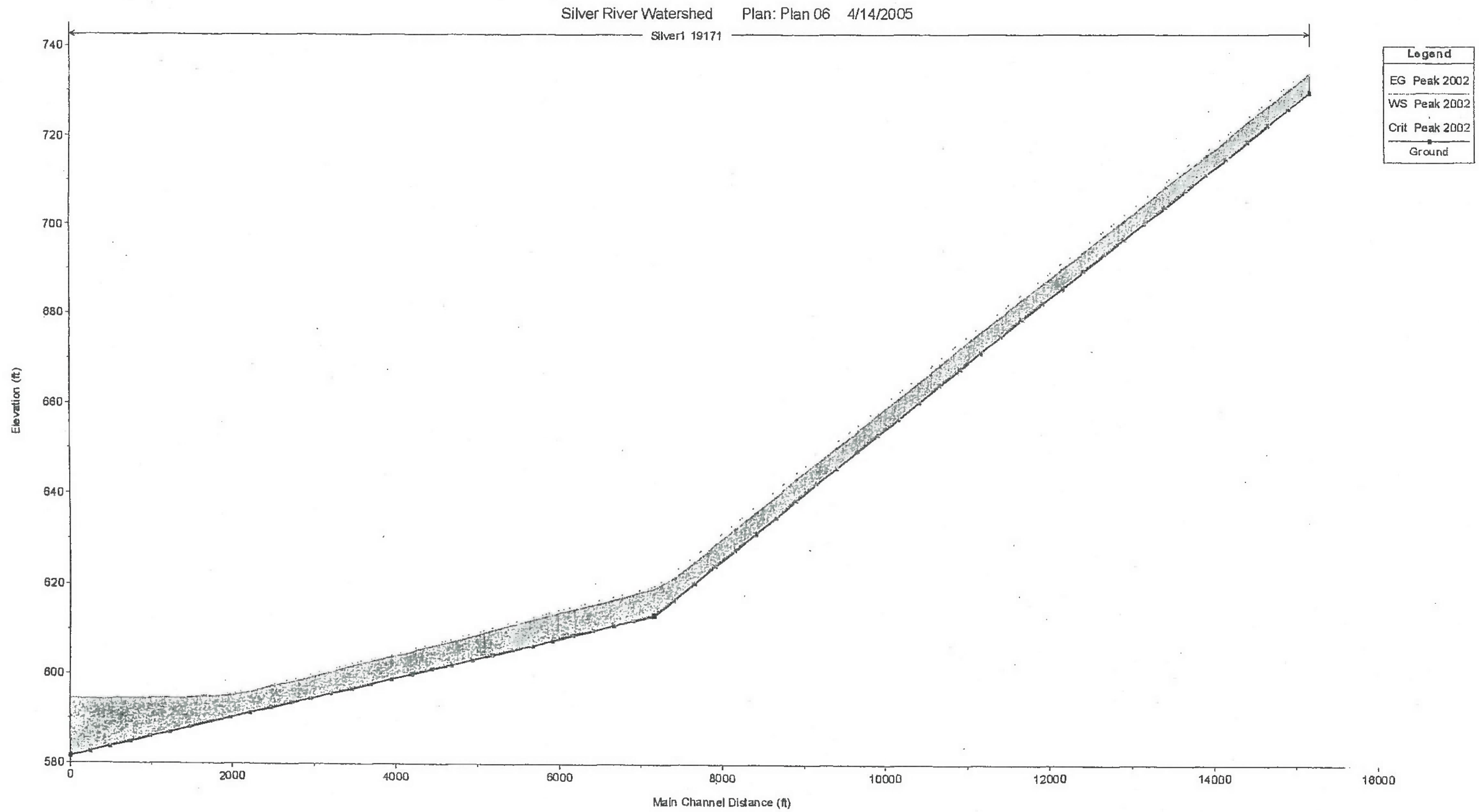

Silver River Watershed Plan: Plan 06 4/14/2005
EastBranch 34181
Elevation (ft)
1550
1500
1450
1400
1350
1300
1250
0
5000
10000
15000
20000
25000
30000
35000
Main Channel Distance (ft)
Legend
EG Peak 2002
WS Peak 2002
Crit Peak 2002
Ground

Gumanche

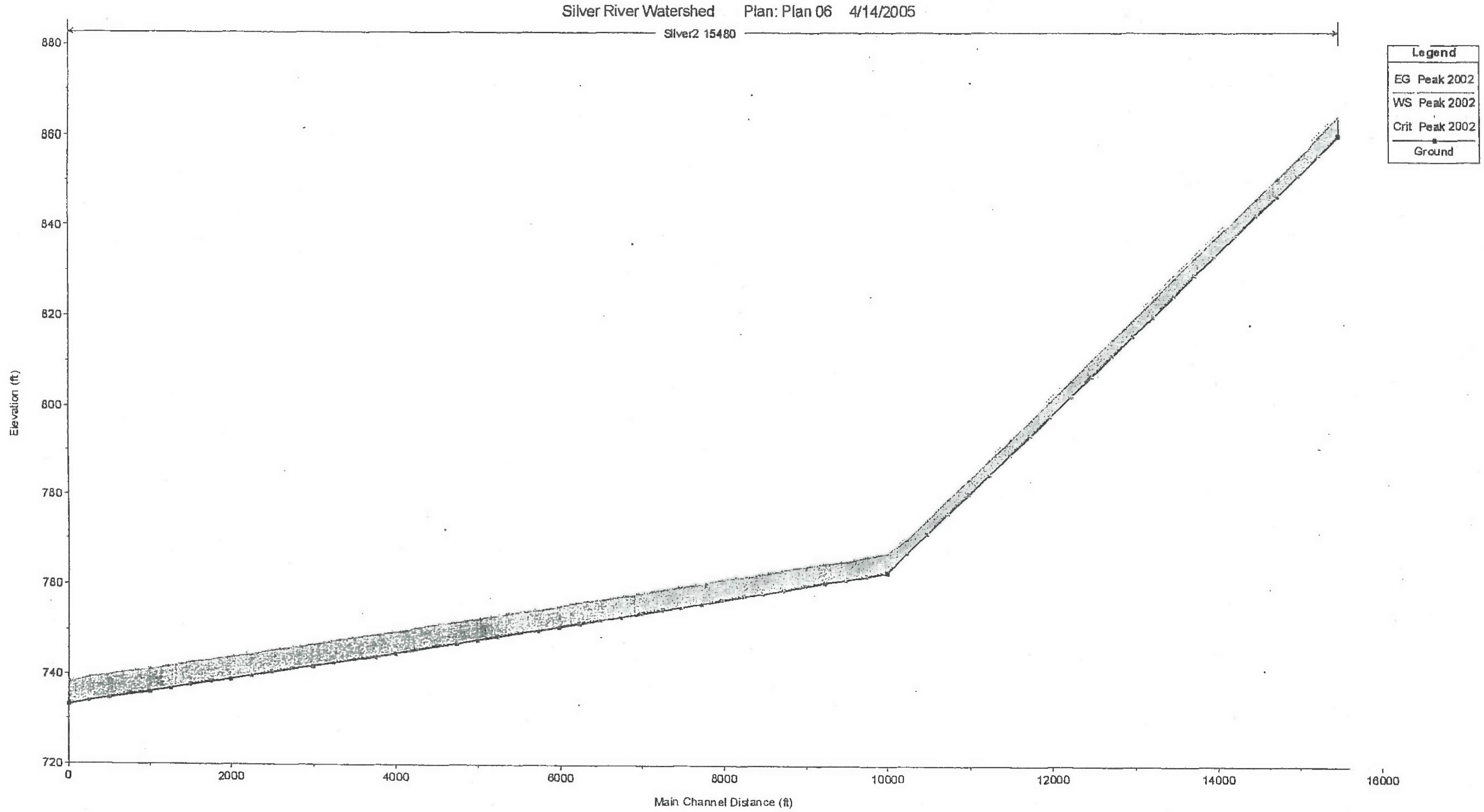


Silver River Watershed Plan: Plan 06 4/14/2005
Gumanche 26154
Legend
Crit Peak 2002
EG Peak 2002
WS Peak 2002
Ground
Elevation (ft)
1250
1200
1150
1100
1050
1000
950
900
850
0
5000
10000
15000
20000
25000
30000
Main Channel Distance (ft)

Silver 1 (most downstream reach)

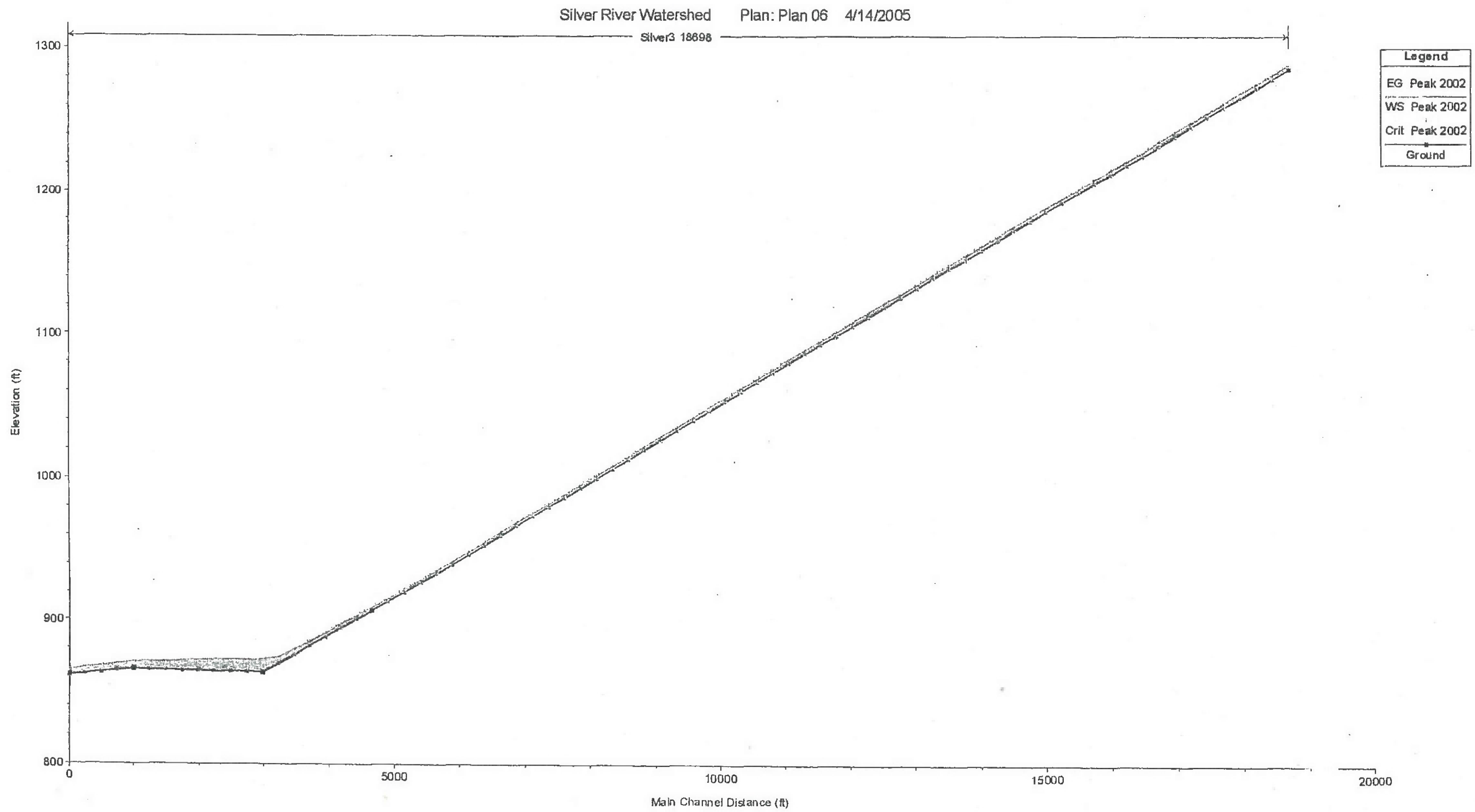


Silver 2

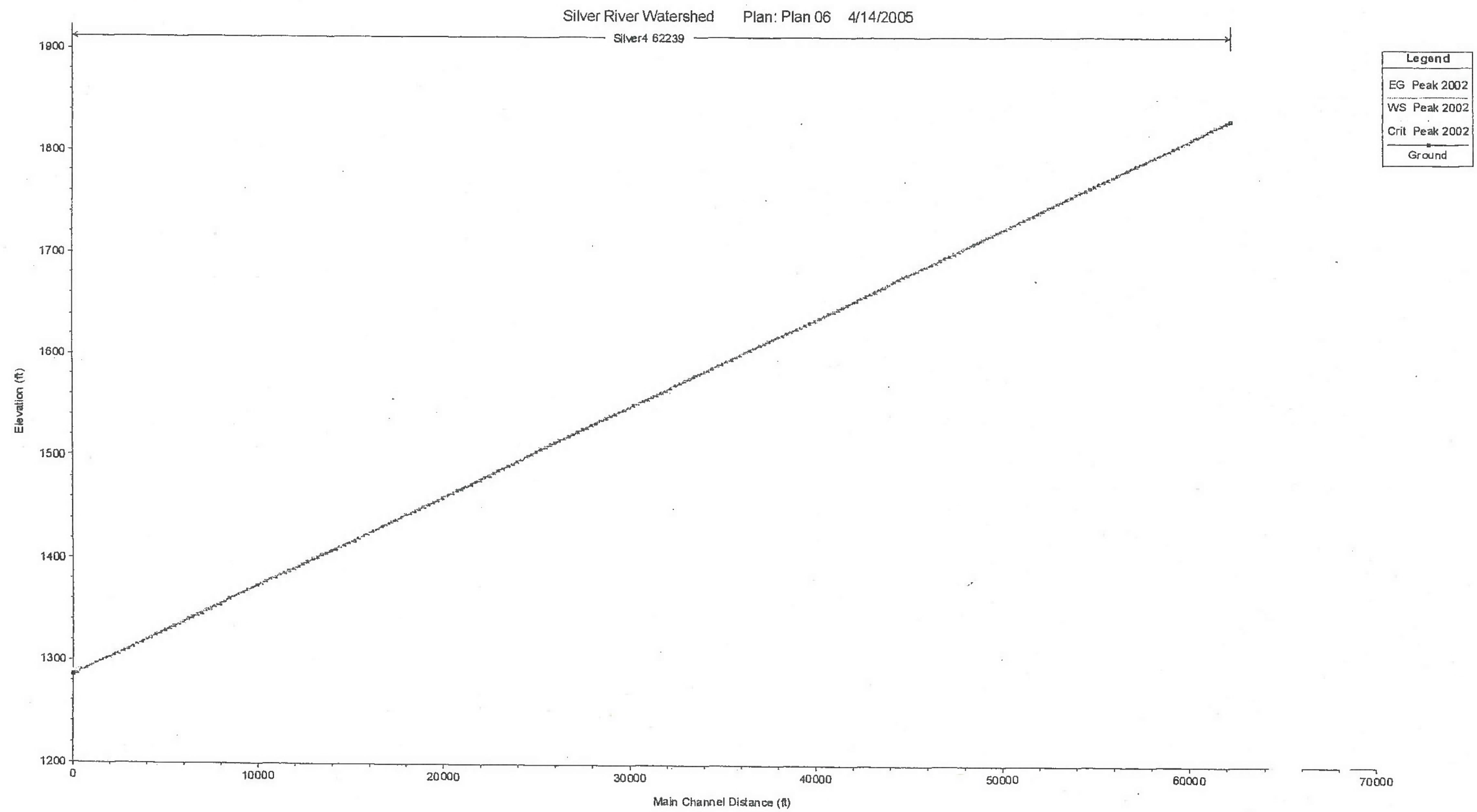


Silver River Watershed Plan: Plan 06 4/14/2005
Silver2 15480
Legend
EG Peak 2002
WS Peak 2002
Crit Peak 2002
Ground
Elevation (ft)
880
860
840
820
800
780
760
740
720
0
2000
4000
6000
8000
10000
12000
14000
16000
Main Channel Distance (ft)

Silver 3


Silver River Watershed Plan: Plan 06 4/14/2005
Silver3 18698
Legend
EG Peak 2002
WS Peak 2002
Crit Peak 2002
Ground
Elevation (ft)
1300
1200
1100
1000
900
800
0
5000
10000
15000
20000
Main Channel Distance (ft)

Silver 4 (most upstream reach)



APPENDIX C – Silver River Region Water Budget

Watershed Calculations	*Area:*	64	sq. miles	
Month	***P*** **(inches)**	***ET*** **(inches)**	***RO+RCHG*** **(inches)**	***RO+RCHG*** **(cfs)**
J	**2.2**	**0.0**	**0.0**	**0**
F	**3.7**	**0.0**	**0.0**	**0**
M	**3.6**	**0.0**	**0.0**	**0**
A	**4.9**	**1.3**	**33.1**	**1901**
M	**2.7**	**2.0**	**43.2**	**2476**
J	**6.6**	**3.8**	**2.8**	**159**
J	**3.9**	**4.6**	**0.0**	**0**
A	**3.9**	**3.6**	**0.0**	**0**
S	**6.8**	**2.7**	**3.7**	**212**
O	**7.9**	**1.1**	**4.8**	**275**
N	**2.6**	**0.0**	**0.0**	**0**
D	**2.0**	**0.0**	**0.0**	**0**
Annual Average:	**50.7**	**19.1**	**87.6**	
Monthly Average:	**4.23**	**1.59**	**7.30**	
Daily Average:	**0.14**	**0.05**	**0.24**	**413**

Month	**Precipitation**	**Snow Pack**	**Snow Melt**	**Soil Moisture**	**Evapotranspiration**	**Runoff & Recharge**
J	57	1645	0	100	0	0
F	93	1738	0	100	0	0
M	91	1828	0	100	0	0
A	125	1079	821	100	33	842
M	69	0	1079	100	52	1096
J	166	0	0	100	96	70
J	98	0	0	81	117	0
A	99	0	0	89	91	0
S	173	0	0	100	68	94
O	202	53	50	100	27	122
N	66	119	0	100	0	0
D	50	169	0	100	0	0

Groundwater Flow Model of the Silver River Watershed
Keweenaw Bay Indian Community, Baraga County, MI

Compiled by: Gina France, Katy Bendall, Megan Lefevre
Department of Geological & Mining Engineering & Sciences
Michigan Technological University, Houghton

Advisor: Dr. John S. Gierke, Ph.D., P.E.
Associate Professor of Geological & Environmental Engineering

Spring ATT Members:
Scott A. Pawlukiewicz, President, Senior B.S.En.E.
Gina M. France, Senior B.S.G.E.
Megan L. Lefevre, Senior B.S.G.E.
Aaron S. Tice, Senior B.S.En.E.
Melissa M. Trahan, Senior, B.S.C.E.
Adam S. Ward, Senior B.S.C.E.
Kathleen A. Bendall, Junior B.S.En.E.
Michael J. McEachin, Junior, B.S. C.E
Benjamin J. Nieto, Junior, B.S.G.E.

May 1, 2005

Executive Summary

The Keweenaw Bay Indian Community (KBIC) of Baraga County, MI obtained Clean Water Act funds to characterize the Silver River watershed, which is part of the Lake Superior Basin in Michigan's Upper Peninsula. A cooperative agreement was established between the KBIC and a student "enterprise" group at Michigan Technological University called Aqua Terra Tech (ATT). ATT was tasked with characterizing the hydrogeological conditions in the watershed and with developing of computer model of the surface and subsurface hydrology. Seasonal home water well levels, shallow seismic refraction, and bedrock outcrops were measured, recorded and mapped by the students and incorporated into a hydrological model using the Groundwater Modeling Systems Software, GMS 5.1. The result of the project is a conceptual model of the regional surface and groundwater flow for the KBIC to utilize for community planning.

Background

Aqua Terra Tech (ATT), an enterprise engineering design student group at Michigan Technological University has completed a collaborative project with the Keweenaw Bay Indian Community (KBIC) to characterize the pristine rural Silver River watershed on the L'Anse Indian Reservation in the Upper Peninsula of Michigan. This project started in the fall of 2000 under the supervision of Dr. John S. Gierke, Ph.D., P.E. Various Civil, Environmental and Geological Engineering students have worked on this project through ATT and senior design. Components of this project included conducting field observations and creating a conceptual computer model of the region surrounding the Silver River watershed.

The geology of the Silver River watershed region is composed of glacial and unconsolidated alluvial deposits overlying intrusive and metamorphic bedrock (Sweat, 1998). Soil types include sandy to silty loams and till based on USDA classification, with some organic soil layers. The watershed area is 64 m^2, with the ground cover being mostly forested with hardwoods, some conifers and swampy areas. The surface topography is generally hilly, with elevation gradients less than sixty degrees from vertical (Kremer, 2001).

Data Sources

The data input into the conceptual model comes from a variety of sources. These sources include field observations; water well drilling borehole records; daily average precipitation data; USGS stream gage data, Digital Elevation Model (DEM), and topographic maps, and USCS Soil Classification data.

Field Observations

The fieldwork utilized for this project includes seasonal water level observations from home drinking water wells from fall 2000-2004, seismic refraction surveys to observe the water table and bedrock elevations, and bedrock outcrop locations. For the water level measurements, a sounder instrument was lowered into the well to measure the water table elevation from the ground surface. When possible, water levels were observed in the same wells from season to season to look at long term variation of the groundwater flow. The seismic refraction surveys were performed at various locations throughout the watershed to expand the geologic data coverage and decrease the error of extrapolation of the water table and bedrock elevations. The surveys were conducted with a 12-channel SmartSeis Seismograph, and locations were verified using a Trimble Global Positioning System (GPS). The bedrock outcrop locations were mapped using the GPS.

USGS Data

The surface water components of the model include rivers, lakes and watershed boundaries. Ephemeral streams were not included in the model for several reasons. The ephemeral streams have a very high seasonal variation which is assumed to average into a static flow value. There is insufficient data to calibrate the calculated stream flow, so the flow from the ephemeral streams is included in the larger river flow. The rivers are established by creating arcs in GMS by tracing a USGS topographic map image backdrop. Inland lakes and the shoreline of Lake Superior are represented as constant head boundaries. The watershed boundaries for the regional model and the sub-watersheds included were determined based on topographic divides. These boundaries were not incorporated in the flow calculations to prevent restriction of groundwater flow according to the topography. Within the region, there are ten watersheds, including the Silver River watershed. The Silver River watershed is divided into seven sub-watersheds based on the tributary stream distribution. This regional approach was used based on previous work in the Zebra Creek watershed, which would not converge on a solution without surrounding regional information.

The ground surface elevations were input through a DEM, based on the UTM NAD1927 coordinate system, with map units set to feet. The DEM originally had a resolution of 100ft grid squares, and this was thinned by taking every tenth elevation point to accommodate GMS computing ability. This yielded a resolution of approximately ¼ x ¼ mile grid squares. The DEM was converted to a triangular irregular network (TIN) layer which was easier for GMS to run simulations with compared to the large DEM file. These elevations allowed GMS to calculate surface water and groundwater flow directions and rates with appropriate spatial distribution.

Groundwater flow also varies based on the hydraulic conductivity of the soil and recharge rates from precipitation. Based on the different soil types according to the STATSGO soil information, regions of for soil types were established in the model. Hydraulic conductivity and recharge were allowed to vary across the region. However, because of the model resolution, GMS was unable to reach a solution using the soil regions. The final model is based on a constant recharge rate and varying hydraulic conductivities.

Model Validation and Numerical Results

As the data was input to the model, simulations of groundwater flow were checked for error, run and checked against observed data. Based on the simulation results, more information was utilized to get the most accurate model possible. This additional information included a flow budget, data from the USGS Silver River gaging station, and comparison to a surface water model using HMS and HEC RAS programs.

The home water well water elevations are not included in the model calculations, but are used to compare calculated water table elevations, or heads. The water level distribution of the Silver River region is shown in Figure 1. Larger figures are found at the end of this report. The home water wells are represented by the relative error compared with the calculated water level elevation. Green error bars are within the specified allowable range of values, yellow error bars are less than 200% error, whereas red error bars represent greater than 200%. Typically, the red wells are outside the Silver River subshed.

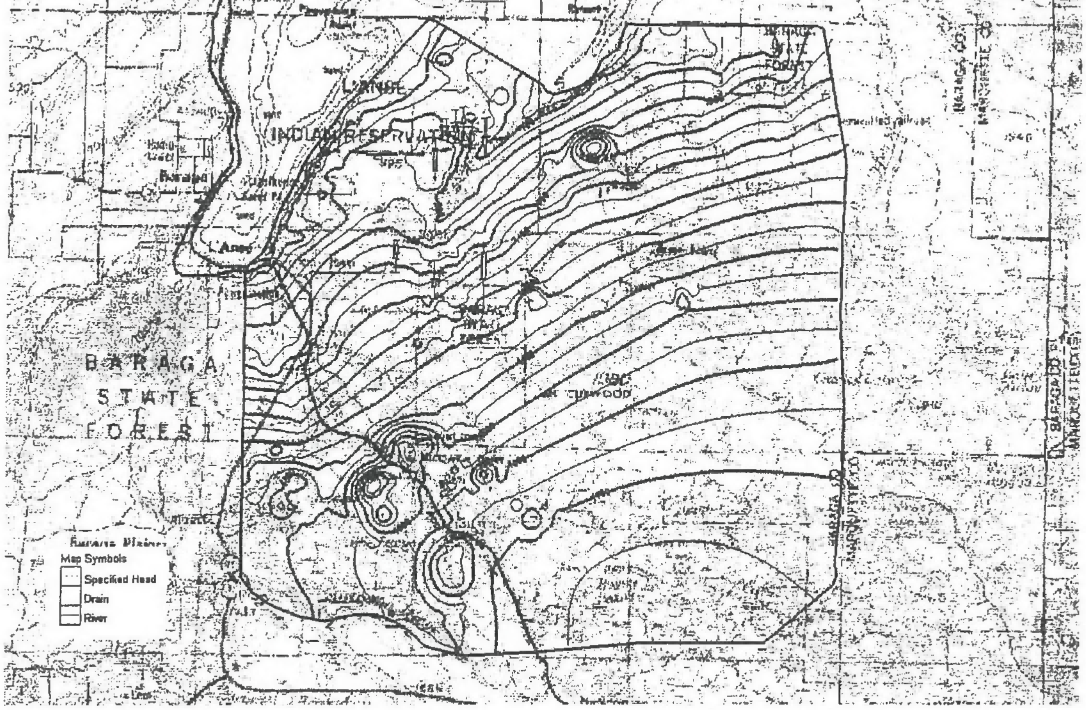


Figure 1. Silver River watershed groundwater table elevation contours. The circular features occur in areas of rapid change in ground surface elevation as well as a higher density of inland lakes.

Figure 2 illustrates the regional groundwater flow direction with flow vectors. The flow vectors are generated independent from the groundwater table elevation contours. Groundwater flow occurs perpendicular to the contour lines, and this shows that the results GMS calculates for the groundwater flow directions are reasonable. A second validation to the relevance of the groundwater flow direction is the watershed boundary images. Groundwater generally flows according to the surface topography, and the generated flow vectors align with the surface watershed boundaries. The flow vectors also show how the groundwater flows in and out of the rivers.

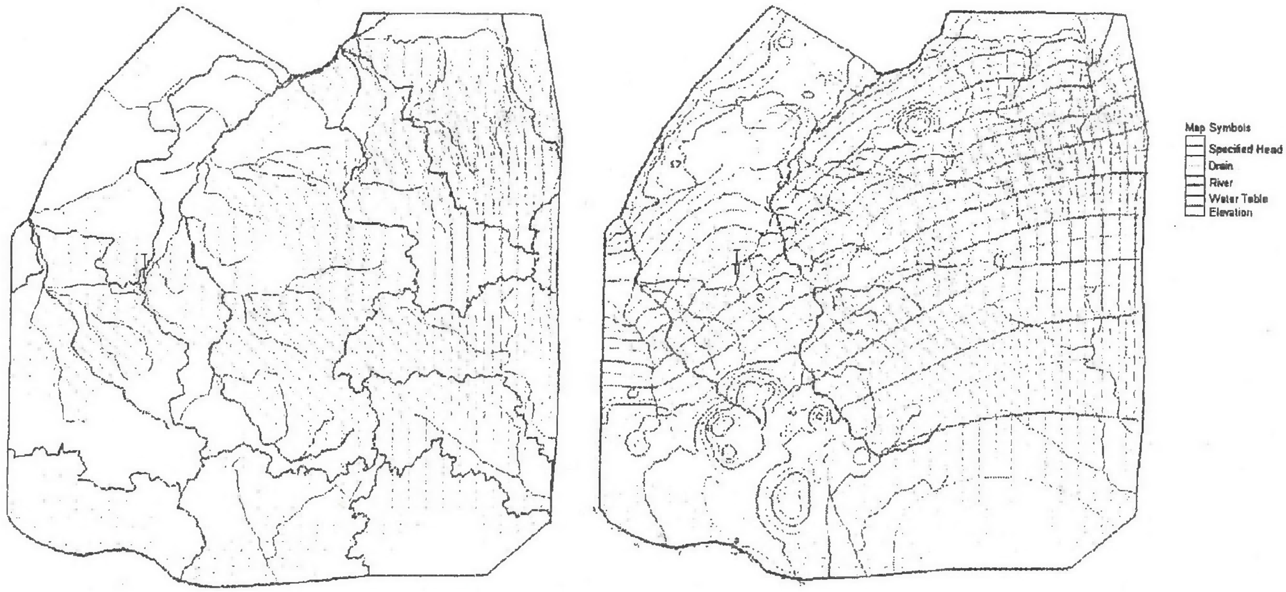


Figure 2. Regional groundwater flow of the Silver River watershed and surrounding areas. The flow vectors generally align with the watershed boundaries. Deviation of flow is likely caused by variation in the subsurface that is not expressed on the surface.

A flow budget was created in GMS to compare the total inflows to the total outflows of the watershed as well as their percentage comparison, which was within 0.00015%. Table 1 shows the ratio of groundwater to surface water discharge into Lake Superior. Based on a USGS study of Lake Michigan, direct groundwater flow into the Great Lakes is typically around 8% of the indirect groundwater flow (Grannemann et al.). Direct groundwater flow includes groundwater going directly from the aquifer into the lake, while indirect flow is groundwater discharged into a surface water body and eventually discharged into the lake. Table 1 gives a ratio of direct to indirect groundwater flow into Lake Superior, which is 5.7%. Though this value is lower than that found for Lake Michigan, it is expected because the aquifers surrounding Lake Michigan typically have higher permeabilities.

Table 1. Flow budget of flow into Lake Superior for regional watershed model.

Groundwater flow (ft^3/d)	Surface water flow (ft^3/d)	Ratio
1,320,000	23,050,000	5.7%

Data from the USGS gaging station was used to calculate observed flow rates from both the groundwater model and the HEC RAS surface water model. The calculated surface water flow rate from the HEC RAS modeling program was compared with the GMS observed flow rate. Although the HEC RAS program does not take into account the evapotranspiration and groundwater flow data, after correction for evapotranspiration the two flow rates for the USGS gaging station location were within 20% of each other. The USGS gaging station was chosen to represent the total surface water flow for the entire watershed because the flow of all subbasins is assumed to flow through the gaging station. Figure 3 shows the correlation of the HEC-HMS surface water flow value locations to those in GMS.

Table 2. Comparison of flow rate results between the HMS and GMS models, as well as adjusted HMS results. The flow through the USGS Gage represents the total flow from all subbasins.

Location	HEC Flow (cfd)	HEC Adjusted (cfd)	GMS Flow (cfd)	Ratio	Adjusted Ratio	% Difference Between Models
USGS Gage	**20206995**	**7216784**	**8965381**	**2.25**	**80.5%**	**19.5%**
Gomanche Creek	1376441	491586	658000	2.09	74.7%	25.3%
East Branch	4779341	1706908	1820106	2.63	93.8%	6.2%
South Sub-basin	5777218	2063292	1040511	5.55	198.3%	98.3%
Junction 1	10556636	3770227	2860617	3.69	131.8%	31.8%
Junction 2	13865602	4952001	4394466	3.16	112.7%	12.7%
Junction 3	18800841	6714586	7963961	2.36	84.3%	15.7%

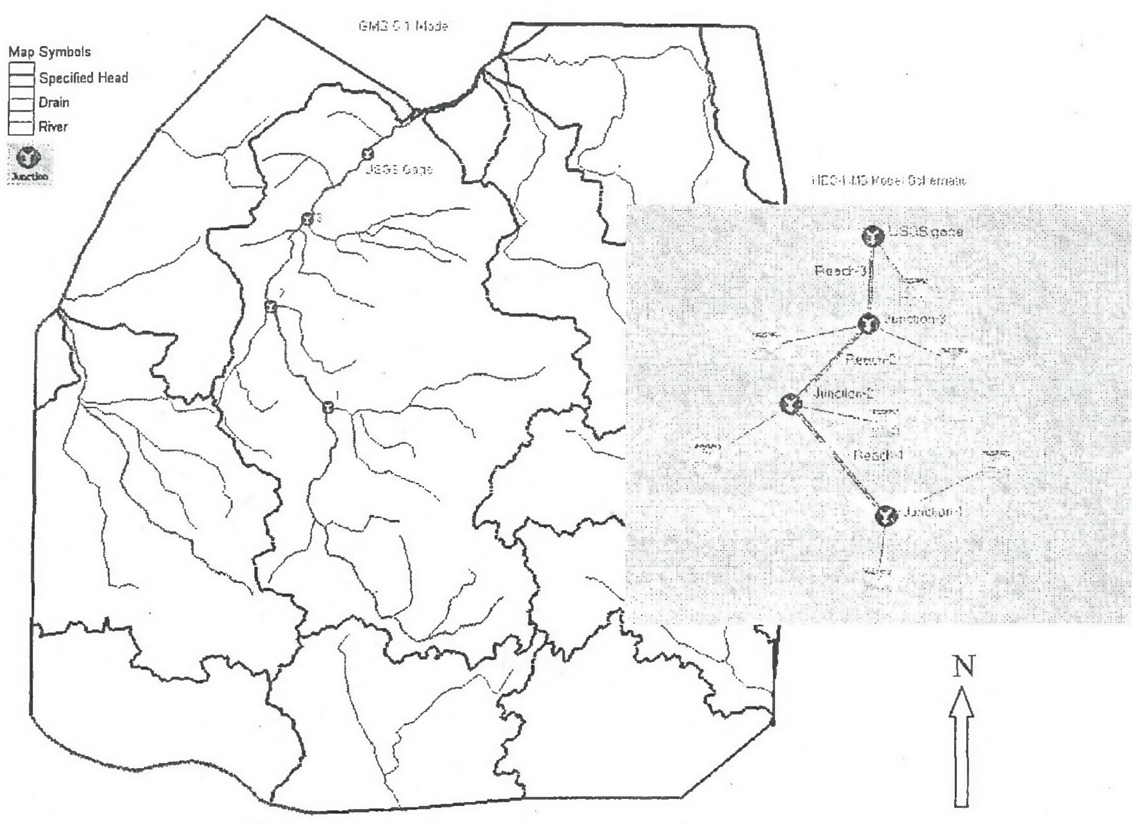


Figure 3. Computer modeled flow rate locations from the GMS 5.1 and HEC-HMS models. Flow values at the junctions are the summation of the total flow upstream of that given point, i.e. the flow through Junction 3 is the sum of all the flows from Junctions 1 and 2 and their respective tributaries.

Conclusions

The groundwater flow in the Silver River watershed region is generally to the northwest, recharging streams from the south. The model calculated water level values had relatively high error from the observed values up to 60 feet, which is most likely due to the low resolution of the elevation data. However, the model calculated groundwater flow direction and the amount of stream flow matches very closely with observed data. The GMS 5.1 model of the Silver River watershed area is a reasonable model given the constraints of the data available and the computational ability of GMS 5.1. Given the large area and variations in the subsurface, the dual layer model was chosen as the best conceptual representation of the watershed behavior.

Additional information that would supplement the model would include a higher resolution of the elevation data, additional stream flow data, and a greater distribution of geologic data in the southeast portion of the watershed. The stream flow data from the gauging station matched the calculated flow, so additional stream gauges would be helpful in modeling the variation of stream flow. Also, estimates of the recharge rates and hydraulic conductivity based on both the soil types and the subsequent geologic layers would enhance the model accuracy. Information that was not crucial to the model was soil data and seasonal water levels at this resolution. A higher resolution model could allow a more detailed variation of recharge and hydraulic conductivity based on both the soils and glacial drift.

Recommendations

Further approaches to the analysis of the watershed would be to first have more information on the recharge rate and hydraulic properties of the watershed. Currently, GMS has the capability to model a higher resolution over a smaller area with more concentrated data. In order to get a higher resolution model, sub-areas of the Silver River watershed could be modeled in greater detail. The results of each of these individual models could be linked to model the entire Silver River watershed. Pending increases in the software, further analysis could include creating a transient model that simulates seasonal variations in the water table.

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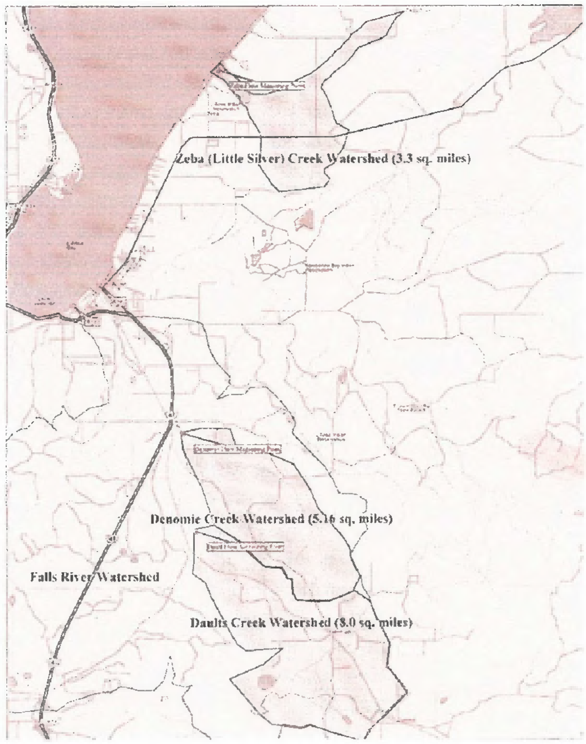

Data Collected by Keweenaw Bay Indian Community Staff and Resident Volunteers

Monitoring Period: May 1999-February 2000

Data Compiled and Interpreted by

John S. Gierke, Ph.D., P.E., 22220 Broemer Road, Chassell, MI 49916

In partial fulfillment of Bureau of Indian Affairs **Aquifer Agreement No. AGF5099001**

Original Report Submitted: 29 December 2000

Summary

Precipitation, stream flow and water chemistry data were collected in three watersheds. Geological information from previous studies and well logs were compiled for the watersheds to characterize the hydrogeological setting. Evapotranspiration rates were estimated based on water budget analysis and independently using monthly temperature and precipitation measurements. Most of the annual precipitation is returned to the atmosphere via evapotranspiration. Annual runoff is only a small percentage of the annual watershed precipitation. More frequent stream flow monitoring is needed to improve the precision of the water budget analyses. Water quality parameters and water table elevations should be monitored at least annually to observe the impacts of changes to the watersheds on water quality and stream flows.

Introduction

Proper management of water resources for sustainable use and protection of water quality requires quantitative knowledge of various components of the hydrologic cycle (precipitation, evapotranspiration, runoff, etc.) and the watershed conditions (area, land use, etc.) and hydrogeological setting (subsurface geology, geochemistry, etc.). Development of quantitative assessments of the hydrological conditions requires field measurements and monitoring of stream flows, precipitation, groundwater levels, and water chemistry. While many of the needed measurements are based on well-established techniques, their applications to particular watersheds and climatic conditions will depend on factors that are regionally specific and maybe specific to a particular location if conditions are unique in terms of the terrain or land use. Therefore, a comprehensive monitoring plan should be flexible and adaptable to local conditions.

The Keweenaw Bay Indian Community (KBIC) has begun to develop comprehensive monitoring and assessments of their water resources, including both surface water and groundwater. Precipitation, stream runoff and chemistry, and subsurface geology were selected as the starting conditions and properties for long-term study. Rather than attempt to monitor all streams and characterize the geology/hydrogeology of the entire Tribal lands, two areas were selected for this preliminary assessment. Smaller watersheds were selected in this first effort to evaluate watershed hydrology, including the subsurface hydrogeology. Zeba (Little Silver) Creek Watershed in Baraga County exists as a single system that discharges directly to Lake Superior (Figure 1). Denomie Creek and Daults Creek are tributaries of the Falls River, and they exist as adjacent watersheds that drain the areas around the community of Herman in Baraga County (Figure 1). Precipitation monitoring was undertaken for the entire reservation by volunteers, mostly tribal residents and one agency (Copper Country Mental Health) and the KBIC Tribal Fish Hatchery. This report is a compilation of the measurements that were obtained during the project period of 1999 and estimates of the hydrology of the Zeba Creek Watershed and the combination of Daults and Denomie Creek Watersheds.

Study Objectives

The overall goal of this study was to gather baseline data on precipitation, stream flows, subsurface geology, and water chemistry for three small, relatively undeveloped watersheds within Tribal lands for the Keweenaw Bay Indian Community. This data was gathered for the following purposes for each watershed:

1. Estimate water budgets

2. Evaluate sampling frequency (areally and temporally) for future monitoring

3. Evaluate the utility of the data for tracking changes in water quality

4. Determine additional data needs and analyses for continued and future monitoring efforts.

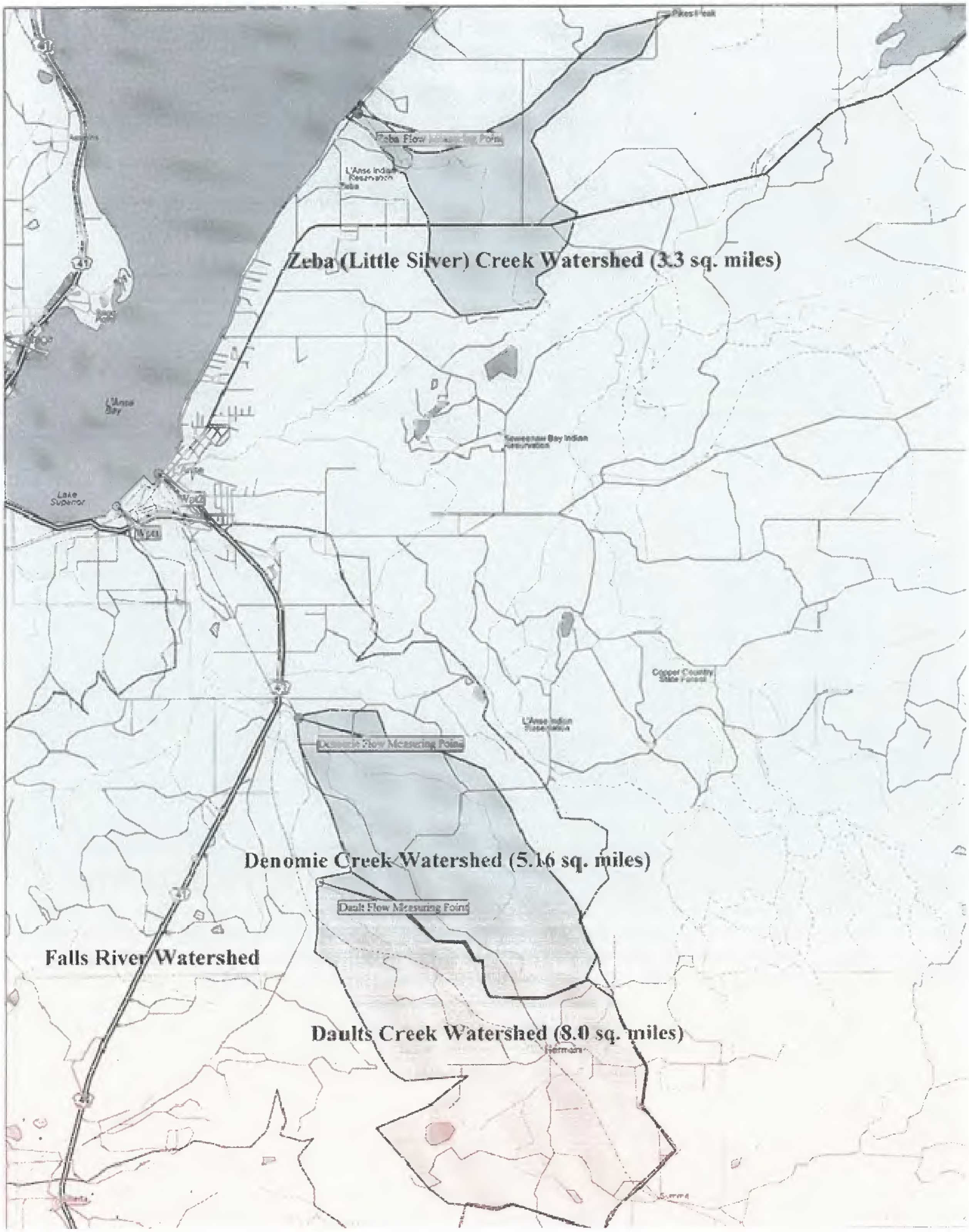

Figure 1. Map showing interpreted watershed boundaries based on USGS topographic contours.

Monitoring

Precipitation

Rain gages were distributed to volunteer residents with a request that they monitor precipitation on a daily basis, starting in May 1999 and continuing through the fall until snow season. The locations of the 16 rain gage locations are labeled in Figure 2 according to the last name of the resident or the name of the agency (Copper Country Mental Health, KBIC Fish Hatchery) that was responsible for the monitoring. Raw data from each location was collected by KBIC staff and put into an Excel spreadsheet. The data was organized by location and date and charts of the results are given in Appendix A. Table 1 is a summary of the observations in terms of the average and peak precipitation events.

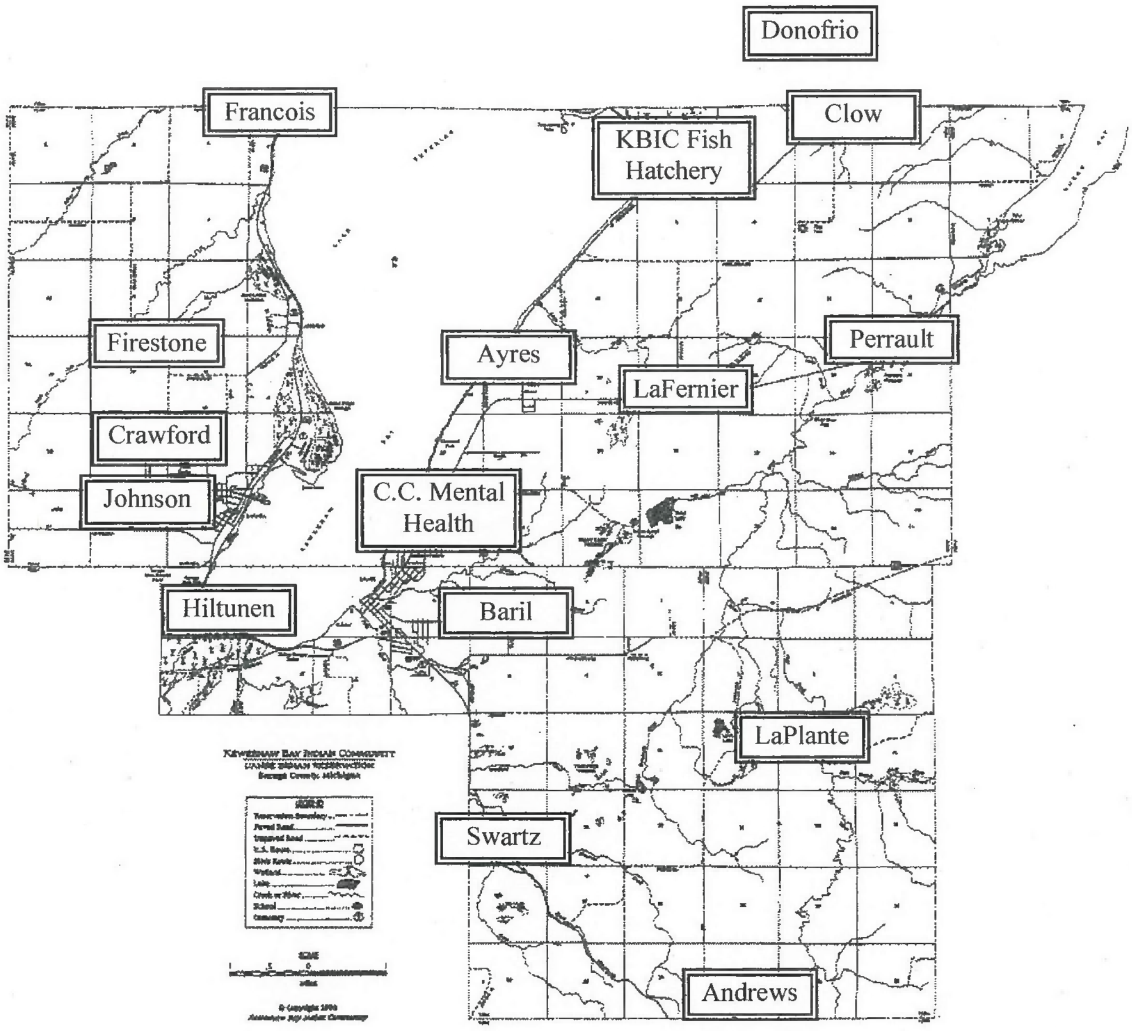

Figure 2. Approximate locations of rain gages monitored by volunteers for spring, summer and fall of 1999. Observations are compiled in Appendix A.

Table 1: Summary of precipitation monitoring by local residents of the KBIC for 1999.

Location	Date Monitoring Started	Date Monitoring Ended	Total Precipitation (Inches)	Total Number Of Days Monitored	Number Of Precipitation Days	Average Daily Precipitation (Inches/Day)	Maximum Precipitation (Inches)	Date Of Maximum Precipitation
Andrew	06/17/99	10/31/99	18.67	137	50	0.14	3.25	07/29/99
Ayres	06/01/99	10/31/99	11.50	153	47	0.08	1.31	06/21/99
Baril	06/05/99	10/31/99	17.42	149	51	0.12	1.97	08/12/99
CCMH	06/14/99	10/31/99	8.34	140	18	0.06	1.94	10/14/99
Clow	05/25/99	10/31/99	16.59	160	56	0.10	1.78	08/12/99
Crawford	06/01/99	10/31/99	17.86	153	63	0.12	1.82	08/13/99
Donofrio	06/15/99	10/31/99	14.35	139	47	0.10	1.92	07/05/99
Firestone	05/21/99	10/31/99	20.12	164	73	0.12	1.70	08/13/99
Francois	06/01/99	10/31/99	15.19	153	46	0.10	1.92	07/06/99
Hatchery	05/01/99	02/29/00	21.82	273	116	0.08	1.40	11/24/99
Hiltunen	05/26/99	10/31/99	8.75	128	24	0.07	1.01	05/31/99
Johnson	06/01/99	10/31/99	16.14	153	55	0.11	1.84	08/12/99
LaFernier	06/15/99	10/31/99	17.31	139	48	0.12	1.12	07/05/99
LaPlante	06/07/99	10/31/99	16.90	147	66	0.11	2.25	06/14/99
Perrault	06/01/99	10/31/99	17.88	153	43	0.12	1.24	06/01/99
Swartz	07/01/99	10/31/99	14.96	123	23	0.12	2.60	09/14/99
Average:			**15.86**	**154**	**52**	**0.10**	**1.82**	
Standard Deviation:			3.70	34	23	0.02	0.57	

On a daily basis the observations varied considerably and appeared to be inconsistent (see Figures A-1 through A-16). However, on overall average basis, the precipitation during the non-snow season (May through October) was consistently about 0.10 inches per day in the higher elevations and 60-80% of this at the Lake Superior elevations (Figure 3). Since the major proportion of the watershed areas reside at the higher elevations, the average precipitation rate of 0.10 inches/day is appropriate for water budget calculations.

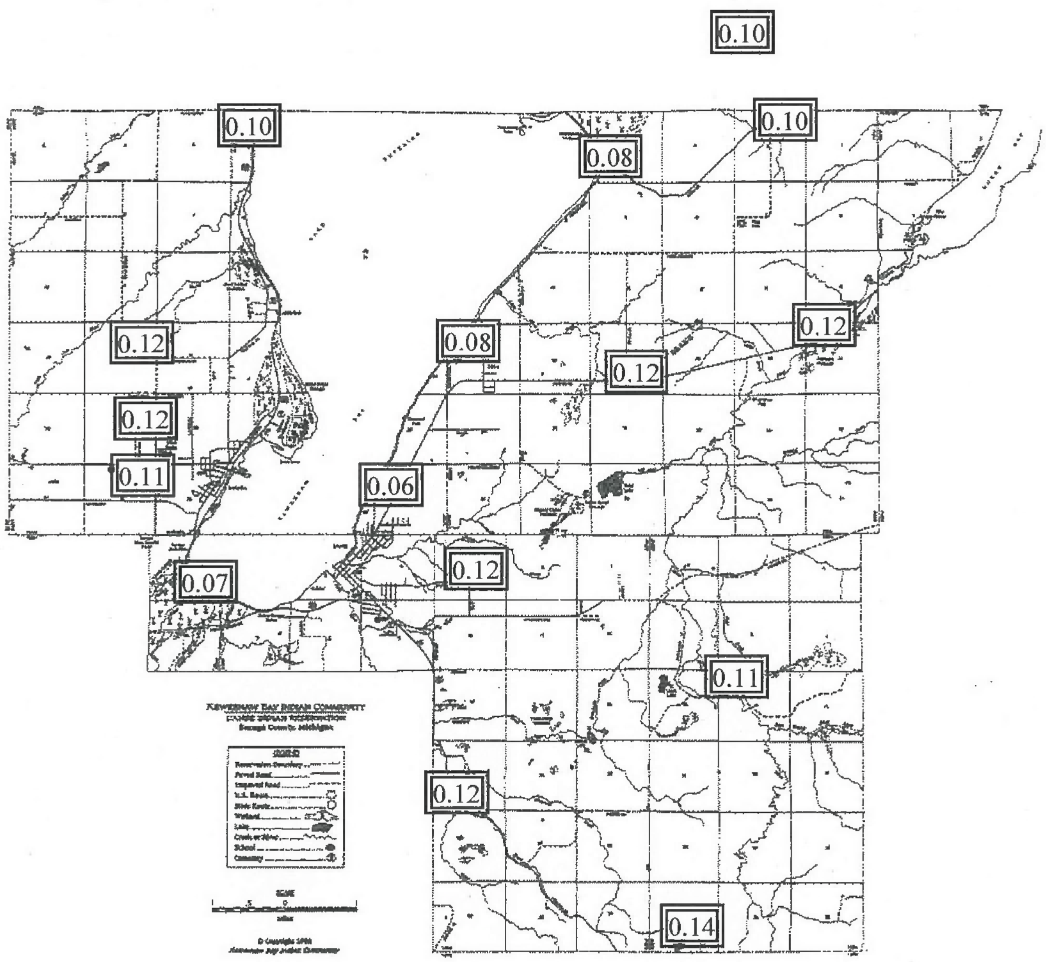

Figure 3. Average daily precipitation (inches/day) monitored by local residents with rain gages between 1 May 1999 and 31 October 1999. The KBIC Hatchery rain gage was monitored from 1 May 1999 through 28 February 2000.

The KBIC Fish Hatchery site had the most complete data set and that site continued collection of precipitation data into the winter. The observations are depicted in Figure 4 (snow data was collected in "water equivalents").

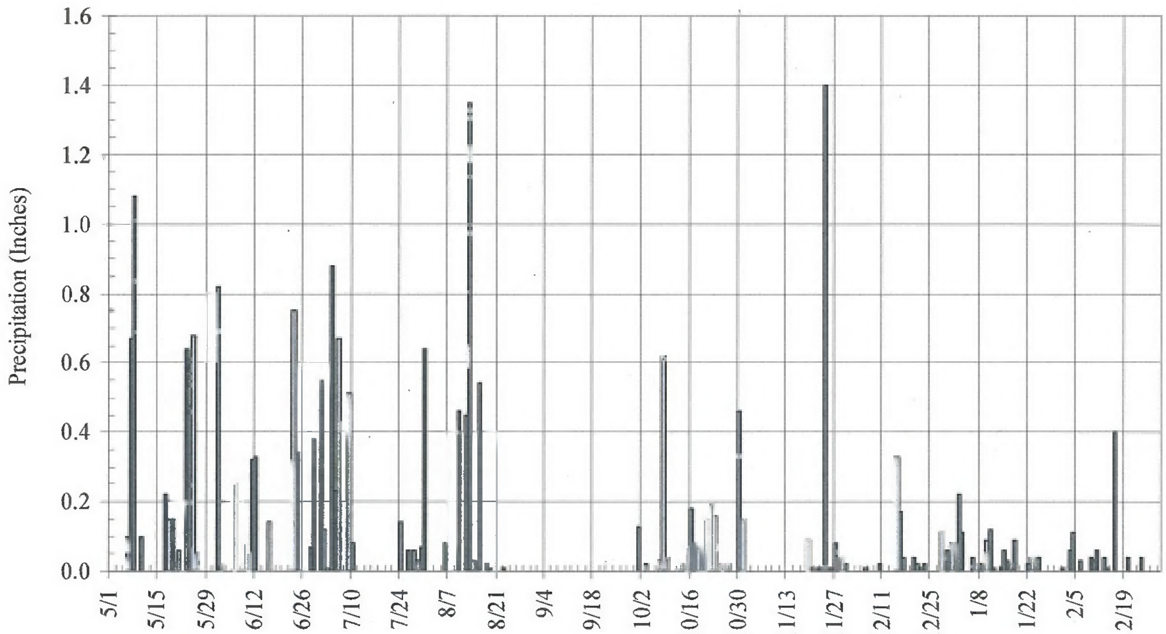

Figure 4. Daily precipitation at the KBIC Fish Hatchery.

Stream Flows

Flow measurements were recorded on a monthly basis in Daults, Denomie, and Zeba Creeks (locations of the measurements are depicted in Figure 1). The flow measurements were made by KBIC staff with a Flow-Mate 2000 (Marsh-McBirney, Inc., Frederick, MD) once a month and at least 2 days after a precipitation event. Daily flow measurements were impractical and so the approach focused on obtaining as close to base-flow conditions as possible. The consistency of the data (Figure 5) suggests that the measurements were precise, however, no independent measures of accuracy are available. Stream chemistry was also evaluated during the flow-measurement activities (see below).

Stream Chemistry

Basic water quality parameters were measured at the same times and locations of flow measurements. The results are tabulated in Table 2. Previously, the Falls River and Zeba Creek were sampled and various water quality parameters were measured by Sweat and Rheaume (1998). The parameters common to this study are listed in Table 2 for comparison purposes. The data are consistent for all applicable parameters except chloride and nitrate+nitrite, which were so low that the discrepancies are probably due to the differences in analytical procedures.

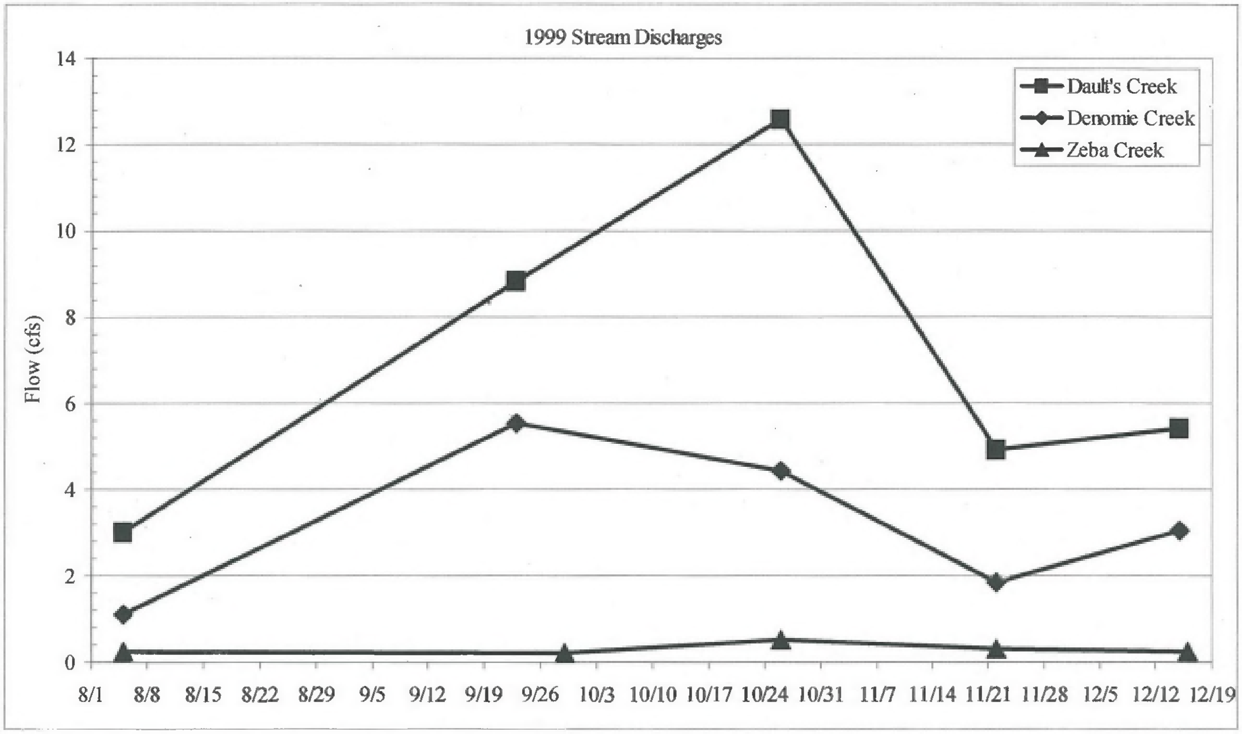

Figure 5. Stream discharges measured in late summer through fall of 1999.

Data Analysis

Water Budget Estimates

A general water budget for a watershed under steady-state conditions follows:

$$\textit{Precipitation} + \textit{Inflows} + \textit{Inputs} = \textit{Evapotranspiration} + \textit{Outflows} + \textit{Withdrawals} \quad (1)$$

Precipitation is the total sum of all atmospheric deposition of rain and snow (in water equivalent). *Inflows* are categorized here as natural sources of water such as groundwater seepage and surface runoff into the watershed. *Inputs* are potential anthropogenic sources such as irrigation, infiltration, and well injections. *Evapotranspiration* is the sum of evaporation and transpiration. *Outflows* are the natural water discharge from streams and groundwater out of the watershed. *Withdrawals* are the result of water extraction from waterwell pumping.

The watersheds in this study area have common characteristics with respect to these hydrological components as listed Table 3. The general water budget can be simplified for these areas to:

$$\textit{Precipitation} = \textit{Evapotranspiration} + \textit{Outflows} \quad (2)$$

Table 2: Stream chemistry measured in the field. Previous data (Sweat and Rheaume, 1998) published (shown in *italics*) for Falls River and Zeba Creek are listed for comparison.

Stream	Date	Time	Conductivity (µS)	pH	Cl (mg/L)	Temperature (C)	Ammonia (mg-N/L)	Acidity (mg-CO_2/L)	DO (mg/L)	Alkalinity (mg-$CaCO_3$/L)	Total Hardness (mg-$CaCO_3$/L)	Nitrate-Nitrite (mg-N/L)
Daults	8/5/99	---	103.1	7.5	0.6	13.4	1.2	35	10	68	86	0
Daults	9/23/99	---	69	7.5	0.6	11.5	0	25	10	51	68	0
Daults	10/26/99	9:30 AM	53.7	8.5	---	4.1	0	---	13	25	43	0
Denomie	8/5/99	---	114.5	7.5	0.6	13.4	2.4	35	9	120	120	0
Denomie	9/23/99	---	155.5	8	0.6	12	0	35	10	103	120	0
Denomie	10/26/99	10:10 AM	133.5	8	---	5.2	0	---	13	78	90	0.01
Falls	*10/30/91*	*12:20 PM*	*145*	*7.8*	*4.4*	*5.0*	*0.01*		*12.8*	*64*	*68*	*<0.05*
Zeba	8/5/99	---	164.7	7	0.6	15.6	1.2	60	10	120	120	0
Zeba	9/29/99	---	177.7	7.5	0.6	8.9	0	25	11	120	120	0
Zeba	10/26/99	11:00 AM	171.8	8.1	---	5.8	0	---	11	96	104	0
Zeba	*10/30/91*	*8:20 AM*	*219*	*7.8*	*4.5*	*3.0*	*0.03*	---	*12.0*	*100*	*110*	*0.50*

Table 3: Water budget components and their significance for the study area.

Water Budget Category	Probable Source/Cause	Estimation Approach	Relative Importance for this Study Area	Comments
Precipitation	Rain and snowmelt	Measured with rain and snow gauges	Primary water input	
Inflows	Overland flow	Assumption	Negligible	Water budget boundary coincides with watershed boundary
	Groundwater inflow	Assumption	Negligible	Water budget boundary coincides with watershed boundary
Inputs	Residential septic fields	Assumption	Balances with waterwell withdrawals	No water from outside the watershed is pumped into the watershed.
Evapo-transpiration	Evaporation and forest transpiration	Thornthwaite method	Nearly equal to precipitation	Watershed is nearly entirely forested
Outflows	Stream discharge	Measurement	Significant but small percentage of total water budget	
	Groundwater discharge	Assumption	Negligible	Area available for discharge is very small, majority of outflow is from stream discharge
Withdrawals	Pumping of residential wells	Assumption	Total extraction is small and is mostly returned to the system via infiltration	Only residential wells exist in the watersheds and since each residence has its own septic/drainfield, the extracted water is returned with very little opportunity for consumptive losses.

Steady-state conditions exist when the system reaches a balance overall between the sum of all inflows and outflows and when waterlevels within the watershed stabilize. Without intensive monitoring, beyond the scope of this study, there is no practical way to justify the assumption of steady-state conditions. Although significant daily, seasonal, and annual variations exist, constructing a water budget over a year-long basis will be representative of annual average conditions as long as no major changes occur in the watershed such as large-scale alterations of land use or water development (e.g., community wells, new dams, etc.). For the areas studied in this project, no substantial changes occurred and so a steady-state flow condition was a reasonable assumption.

For watersheds where precipitation, evapotranspiration, and stream runoff are the predominant components, the stream runoff will be equivalent to the *net infiltration* (precipitation – evapotranspiration) in the watershed. Precipitation can be monitored directly. Evapotranspiration (ET) can not be measured directly and is usually either an estimated property based on other directly measured conditions (e.g., temperature) or inferred by solving the water budget equation for ET. Consider, first, the Zeba Creek watershed where the average annual precipitation was approximately 36 inches (3.0 ft) of water. The average baseflow, based on the four months of monitoring, was 0.25 cfs. The watershed encompasses an area of 3.3 square miles (93,000 ft^2). Therefore, the water budget for Zeba Creek in terms of <u>measured</u> quantities is:

$$3.0 \text{ ft/yr} \times 93{,}000{,}000 \text{ ft}^2 = \text{ET} \times 93{,}000{,}000 \text{ ft}^2 + 0.25 \text{ ft}^3\text{/s} \times 31{,}536{,}000 \text{ s/yr}$$

which yields an estimate of the annual ET for the Zeba Creek watershed of 2.9 ft. Therefore, the infiltration within the watershed is less than 5% of the annual precipitation. This difference is within the error of the measurements in precipitation and stream flow, and thus the stream flow component of the water budget is statistically insignificant for the Zeba Creek watershed.

Evapotranspiration rates are also often estimated based on climatological data (daily temperature, wind speeds, solar radiation, etc.) and soil and vegetation conditions. Only precipitation and temperature data exist for the watersheds in this study, so the Thornthwaite method is probably the most suitable approach for independently estimating ET. The details for calculating ET by the Thornthwaite method are given by Sellinger (1996) and the results using Sellinger's computer program (cf. ftp://ftp.glerl.noaa.gov/publications/tech_reports/glerl-101) are listed in Table 4 for the conditions observed at the KBIC Fish Hatchery.

The Thornthwaite method uses measurements for monthly mean precipitation and temperature, along with a general characterization of soil and vegetation conditions, to estimate actual ET. Other methods require measurements of other parameters such as wind speed, solar radiation, and dew point. A more sophisticated approach would not necessarily yield an estimate with a higher degree of accuracy, nor is a higher degree of accuracy warranted.

Table 4. Evapotranspiration (ET) estimates for the Keweenaw Bay region. Estimates of Actual ET were calculated using the Thornthwaite method using measured mean monthly temperature (daily temperatures are shown in Appendix B: Figure B-1) and precipitation (from Figure 4) at the KBIC Fish Hatchery.

Month	Year	Mean Temperature (Celcius)	Precipitation (mm)	Precipitation (inches/day)	Actual ET (mm)	Actual ET (inches/day)
May	1999	12	111	0.146	78	0.102
June	1999	17	90	0.118	113	0.148
July	1999	20	103	0.135	132	0.173
August	1999	18	75	0.098	105	0.138
September	1999	12	66	0.087	66	0.087
October	1999	7	58	0.076	31	0.041
November	1999	5	43	0.056	19	0.025
December	1999	-3	25	0.032	0	0.000
January	2000	-5	24	0.031	0	0.000
February	2000	-2	22	0.029	0	0.000
Total			**546**		**544**	
Average		*8*		*0.059*		*0.059*

Figure 6 graphically depicts the measured monthly precipitation and estimated actual evapotranspiration from May 1999 through February 2000. Seasonally, when precipitation exceeds ET, then the excess precipitation is, in varying proportions, infiltrating the soils and running off into streams. During the summer when ET exceeds precipitation, then groundwater is supplying the stream flow and also being drawn towards the ground surface by capillary action to replenish soil moisture lost to ET.

Overall, the Thornthwaite method suggests a balance between precipitation and evapotranspiration for this study area, which is common for heavily forested watersheds lacking in development that significantly alters infiltration. The same results also apply to the Denomie and Daults Creek watersheds.

A balance between precipitation and evapotranspiration is important from the perspective of land development. Development that negatively affects infiltration and/or enhances evaporation (transpiration is probably already at a maximum for the areas in this study), will result in decreased water supplies and reductions in stream flows. There are no practical alterations that could increase transpiration, as the transpiration rate is probably already near the maximum for these areas considering the dense vegetation. Changes that would cause an increase in the evaporative component would cause a concomitant decrease in transpiration. Hence the ET rate is, for all intensive purposes, fixed according to the average near-surface soil conditions.

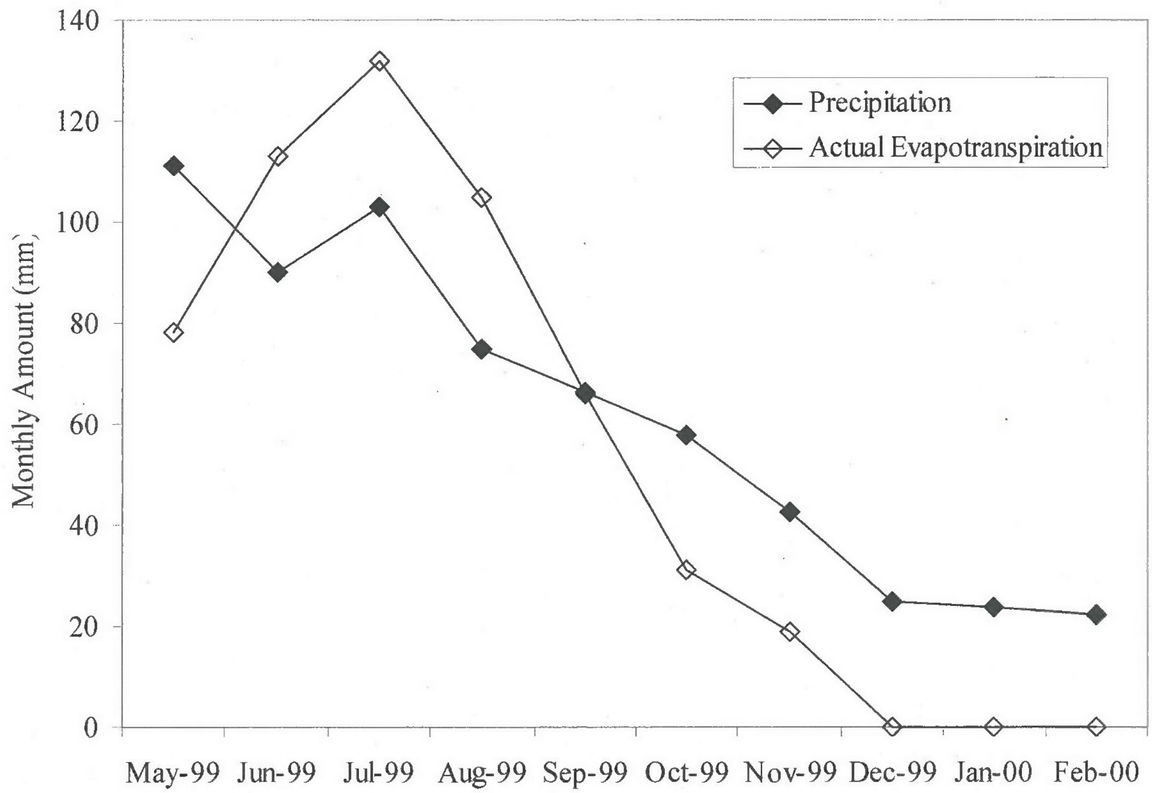

Figure 6. Comparison of average monthly precipitation to an estimate of actual evapotranspiration based on the Thornthwaite method using mean monthly precipitation and temperatures observed at the KBIC Fish Hatchery.

Geological Conditions

Well log records, from the locations listed and summarized in Table 5, were reviewed for the areas included in this study.

The Zeba creek watershed is primarily underlain by Jacobsville sandstone, according to Doonan and Byerlay (1973) and confirmed by the well logs. The surficial deposits (overburden) are primarily are ground and water-laid moraine deposits, made up of loose till, containing beds of lacustrine sand and poorly sorted gravel (Doonan and Byerlay, 1973), and vary in thickness from a few feet to 80 feet and more. The well logs in the Zeba creek watershed could be characterized into two categories based on overburden thickness: (1) “thin” overburden is less than 30 feet deep and (2) “thick” overburden is more than 30 feet deep.

Table 5: Summary of available well logs and general geological conditions.

Township Number (N)	Range Number (W)	Section Number	Watershed(s)	Number of Wells in Section	Generalized Geological Description
50	32	31	Denomie	1	thin overburden above bedrock (not identified)
50	33	15	Denomie	4	thin overburden above bedrock (some not identified, slate, and granite)
50	33	22	Denomie & Daults	9	thin overburden above bedrock (some not identified, slate), one well in thick overburden never reaching bedrock
50	33	26	Denomie	1	thick overburden above slate
50	33	27	Denomie	1	thick overburden above slate
50	33	35	Denomie	1	thick overburden above slate
50	33	36	Denomie	2	thick overburden above bedrock (not identified)
51	32	16	Zeba	1	thin overburden above sandstone
51	32	18	Zeba	6	thin-thick overburden above sandstone
51	32	20	Zeba	5	thin overburden above sandstone with underlying shale
51	32	21	Zeba	13	thin overburden above sandstone

The term "thin" overburden refers herein to a thickness of less than 30 ft; "thick" overburden refers to deposits more than 30-ft thick. Bedrock thicknesses were typically not determined as the boreholes did not penetrate the entire unit.

Most of the Falls River watershed, which includes both Denomie and Daults watersheds, is underlain by metamorphic rocks, primarily slate, according to Doonan and Byerlay (1973) and most of the well logs. Many of the well logs referred to the rocks only as "bedrock," but it is reasonable to assume that the drillers were referring to slate. The most southeastern edge of the watersheds overlies granite and/or gneiss (Doonan and Byerlay, 1973), but data for this region is lacking and only one well log indicates that granite was present. In the region around where Denomie and Daults creeks discharge into the Falls River (northwestern-most third), the surficial deposits are of the same origin as in the Zeba Creek watershed. This comprises about one-third of their watershed areas. The surficial deposits in the middle third of both watersheds is characterized by higher elevation moraine deposits that are primarily more compacted till. The uppermost third of the watersheds (southeastern-most third) are very thin and bedrock outcrops at the surface are common, but some localized deposits of recent alluvium (Doonan and Byerlay, 1973) surround the community of Herman and comprise the headwater of Daults Creek. Well logs for the Herman area were not evaluated as they are outside the reservation.

Hydrogeological Conditions

Potentiometric maps of the study areas have been prepared and published by Doonan and Byerlay (1973) and Sweat and Rheaume (1998). These maps are consistent with the general assumption that regional groundwater flow follows the surface topography (cf. Freeze and Cherry (1979)). Large pumping wells, irrigation and infiltration systems, and hydraulic structures such as dams can cause subsurface flows to deviate significantly from the topographic trends, but none of these conditions exist in this study area. Therefore the general flow direction is trending toward the northwest for both the Falls River and Zeba Creek watersheds. The water table tends to vary between 6 to 70 feet below ground surface across the study area, but for most wells the water table is between 10 and 30 feet deep.

All of the wells in the study area were residential and installed using either cable-tool or rotary drilling methods by local drilling contractors. Well diameters were usually between 4 and 8 inches and installed to depths of 100-300 feet. Steel casing extended from a foot or so above the ground surface to a few feet into the bedrock, so the pumped water was being drawn through the bedrock into an open borehole. In general, well productivity would be greatest for aquifers in unconsolidated deposits, but most of the glacial drift lies either above the water table or the saturated thickness in these deposits is too shallow for acceptable yields. Well capacities for bedrock aquifers are typically highest in sandstone, lower in slate, and then lowest in granite and gneiss.

Drillers test the well capacity by monitoring the pumping water level and pumping rate for periods ranging from a few hours to two days or until the pumping level falls below pump intake, which occurs when well yields are low. Well performance varied from less than 1 gallon per minute (gpm) to as much as 30 gpm of sustainable flow. About half of the wells in the sandstone aquifers yielded sustainable flows of 5 gpm or more; only 20% of the wells in the slate bedrock aquifers produced at a sustainable rate.

With a few exceptions, the productivities of wells in the Zeba creek watershed varied inversely with overburden thickness. In general, the wells with an overburden less than 30-ft thick yielded sustainable flows (~5 gpm) and the wells where the glacial drift deposits were thicker than 30 feet would usually be pumped "dry," which is the temporary condition where the water level in the pumping well falls below the pump intake and the pumping is stopped until the well recovers. One explanation for the curious inverse trend between overburden thickness and well capacity is that the sandstone underlying the regions of thin overburden is more fractured, which is where the highest proportion of flow is occurring (Sweat and Rheaume, 1998). The more weathered and fractured sandstone was probably eroded during glacial retreat, producing areas where the glacial drift is thick. Therefore the wells where the glacial drift is thick are drawing water from sandstone that is probably less fractured and tighter than the wells where the glacial drift is thin. Better yields might be obtained from some wells by installing a properly designed screen in the lower most portion of the glacial drift, if the water table is 40 feet or more above the bedrock and the glacial deposits do not exhibit significant fractions (e.g., >10% by weight) of fine materials.

The wells in the Daults and Denomie watersheds were less productive. Only 20% of the wells could produce sustainable yields of 5 gpm or more. There were no clear trends that would suggest where the probability of yielding a productive well is greatest, probably because the productivity of a given well is a function of whether it intercepted a sufficient number of water-producing fractures.

Conclusions

Precipitation monitoring during the May through October of 1999 observed a range of average daily precipitation of 0.06 inches/day at L. Superior elevations to 0.12 inches/day at the higher elevations. Daily precipitation monitoring at elevations representative of the variation within a watershed are needed.

The Thornthwaite method for estimating evapotranspiration was consistent with waterbudget estimates of evapotranspiration. Most of the precipitation is returned to the atmosphere via evapotranspiration for the three watersheds in this study.

Stream flows were measured on a monthly basis in Zeba, Daults, and Denomie creeks. Monthly stream-flow monitoring was not frequent enough to yield an accurate water budget analysis and to provide data that will be needed to observe seasonal and other short-term changes in stream flows and water quality. Stream gauging stations that can be monitored at least weekly should be considered for more comprehensive watershed studies.

Stream flows represent a small percentage of the annual transfer of water in a watershed and are influenced significantly by short-term precipitation events. Water table elevations will provide baseline data for monitoring long-term changes in the hydrology of a watershed, and a systematic approach for monitoring water table elevations should be implemented.

Water quality in terms of chemical parameters has not changed significantly since 1991 (no data exists prior to 1991) for Zeba, Denomie, and Daults Creeks. Sedimentation of creeks is a concern throughout the Upper Peninsula and stream-borne sediment transport should be included in all future monitoring programs.

References (cited in the report)

Doonan, C.J., and J.R. Byerlay (1973). Ground Water and Geology of Baraga County, Michigan, State of Michigan, Lansing, Michigan, 26 pp. and 2 maps in pocket.

Freeze, R.A., and J.A. Cherry (1979). Groundwater, Prentice-Hall, Inc., Englewood Cliffs, New Jersey, 604 pp.

Sellinger, C.E. (1996). Computer Program for Estimating Evapotranspiration Using the Thornthwaite Method, NOAA Technical Memorandum ERL GLERL-101, Great Lakes Environmental Research Laboratory, National Oceanic and Atmospheric Administration, Ann Arbor, November 1996.

Sweat, M.J., and S.J. Rheaume (1998). Water Resources of the Keweenaw Bay Indian Community, Baraga County, Michigan, U.S. Geological Survey, Denver, Colorado, 33 pp.

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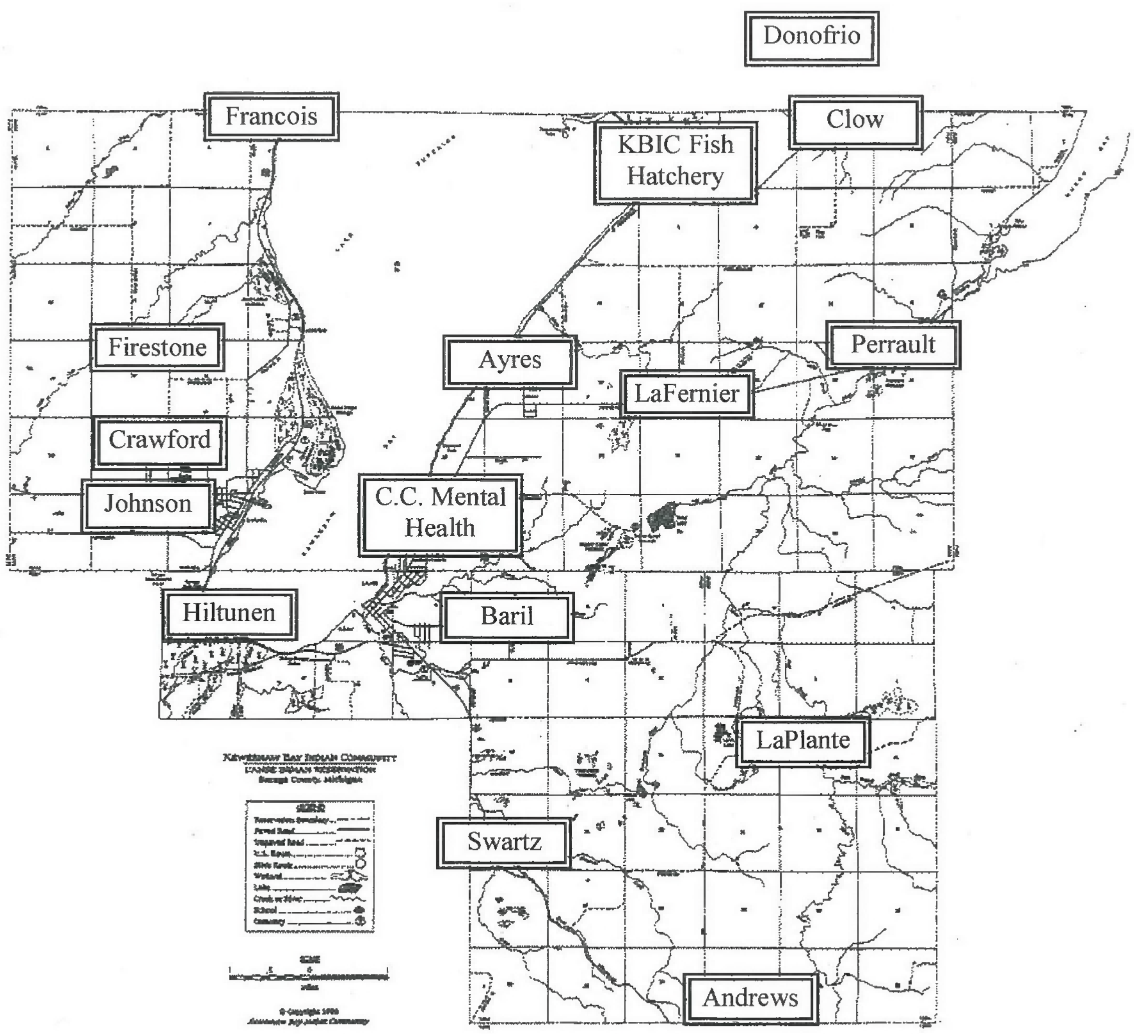
Berndt, L.W. Soil Survey of Baraga County Area Michigan, U.S. Department of Agriculture Soil Conservation Service, 306 pp. plus maps.

Farm and Home Publishers, LTD. Baraga County Michigan Plat Book, Belmond, IA, 64 pp.

Stone, W.J. (1999). Hydrogeology in Practice: A Guide to Characterizing Ground-Water Systems, Prentice Hall, Upper Saddle River, New Jersey, 248 pp.

Appendix A. Rain gage monitoring in Baraga County for 1999 by local residents and two local agencies. Locations are shown in figure below.



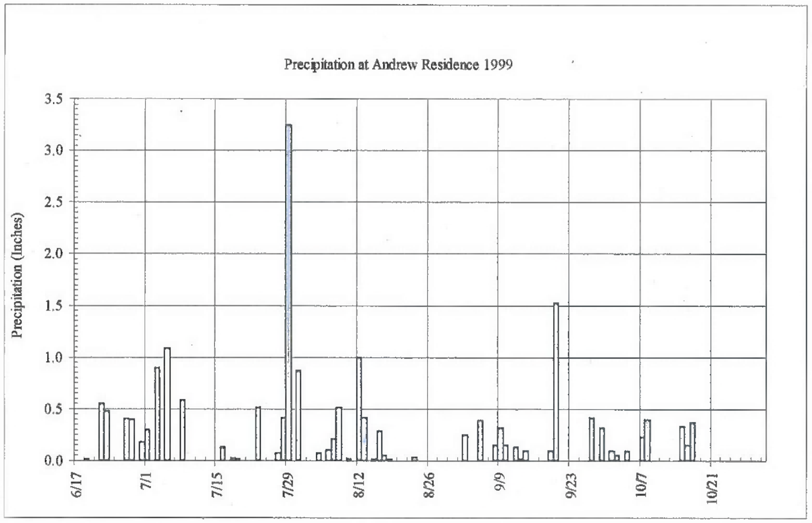


Figure A-1. Precipitation monitored at Andrews residence (Baraga County, MI) in 1999.

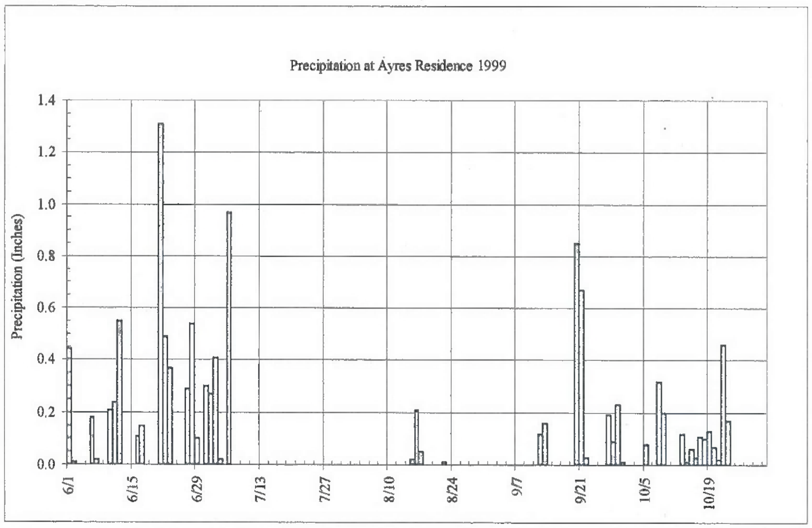


Figure A-2. Precipitation monitored at Ayres residence (Baraga County, MI) in 1999.

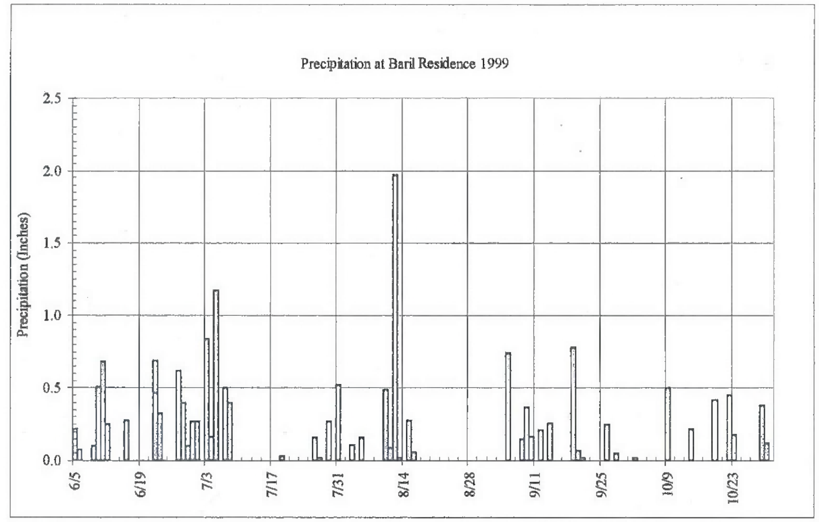


Figure A-3. Precipitation monitored at Baril residence (Baraga County, MI) in 1999.

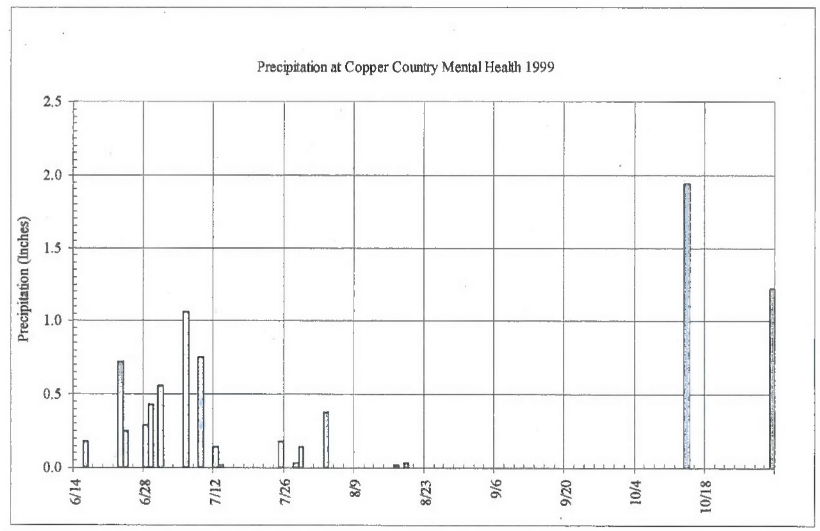


Figure A-4. Precipitation monitored at Copper Country Mental Health (Baraga, MI) in 1999.

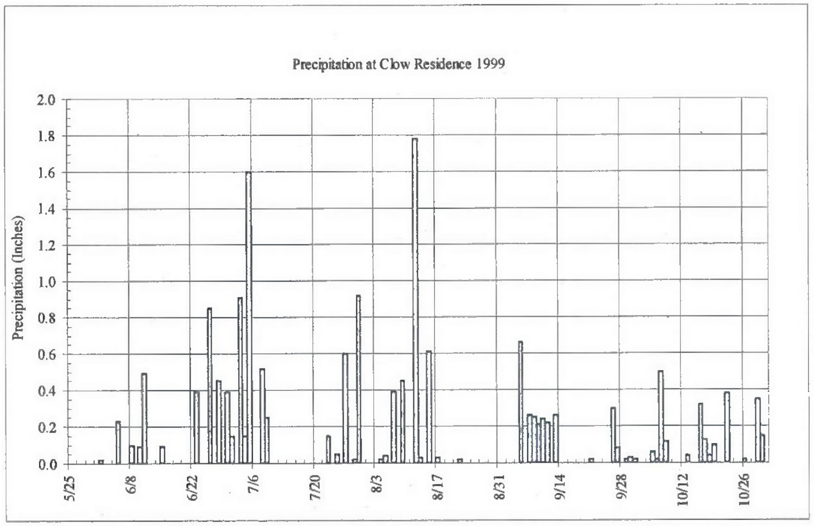


Figure A-5. Precipitation monitored at Clow residence (Baraga County, MI) in 1999.

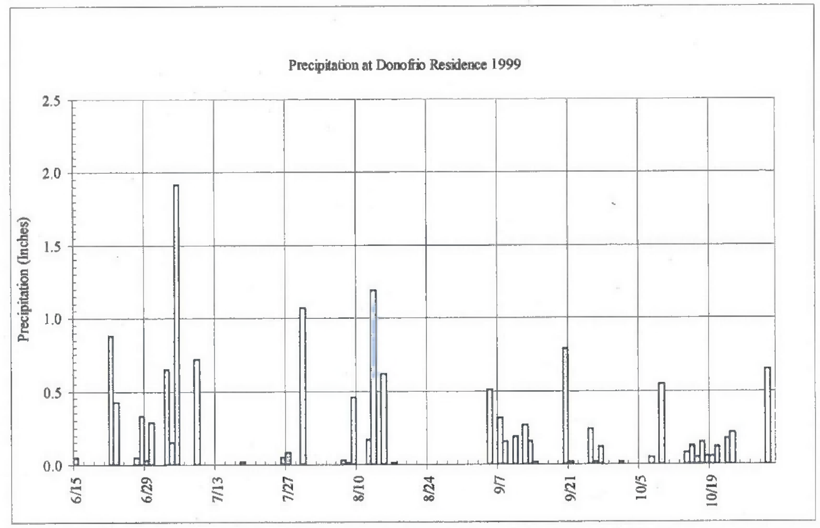


Figure A-7. Precipitation monitored at Donofrio residence (Baraga County, MI) in 1999.

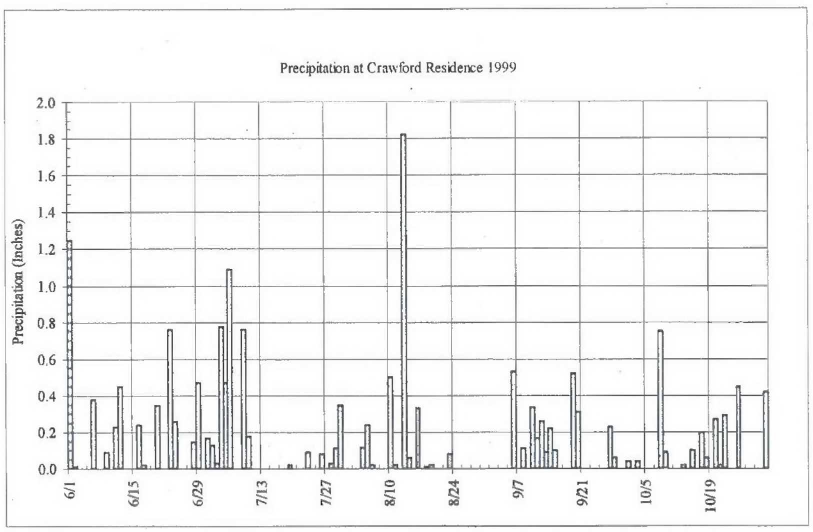


Figure A-6. Precipitation monitored at Crawford residence (Baraga, MI) in 1999.

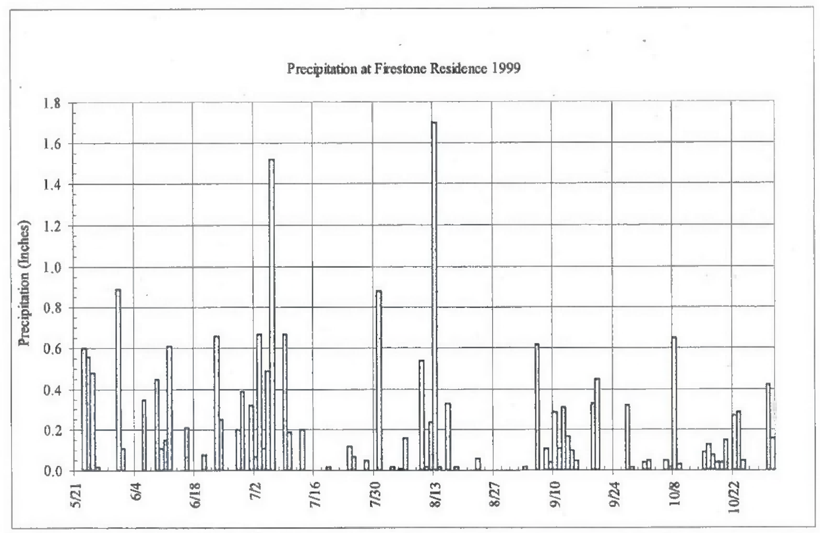


Figure A-8. Precipitation monitored at Firestone residence (Baraga, MI) in 1999.

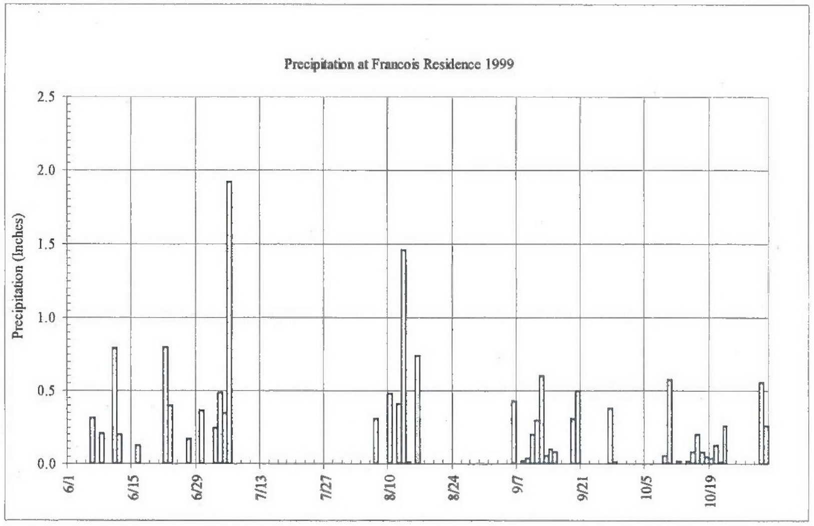


Figure A-9. Precipitation monitored at Francois residence (Baraga County, MI) in 1999.

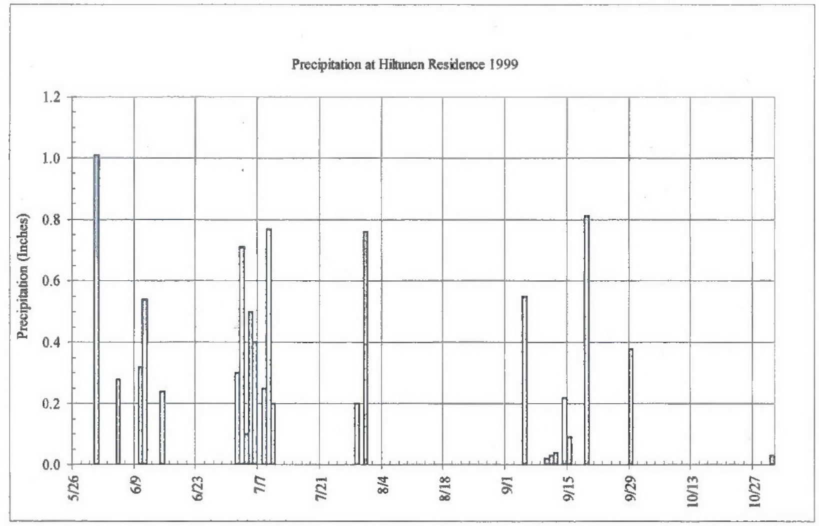


Figure A-11. Precipitation monitored at Hiltunen residence (Baraga County, MI) in 1999.

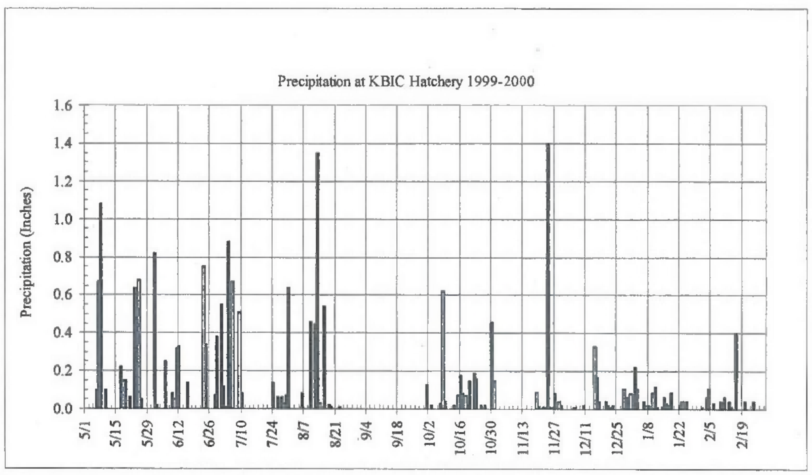


Figure A-10. Precipitation monitored at KBIC Tribal Fish Hatchery (Baraga County, MI) in 1999.

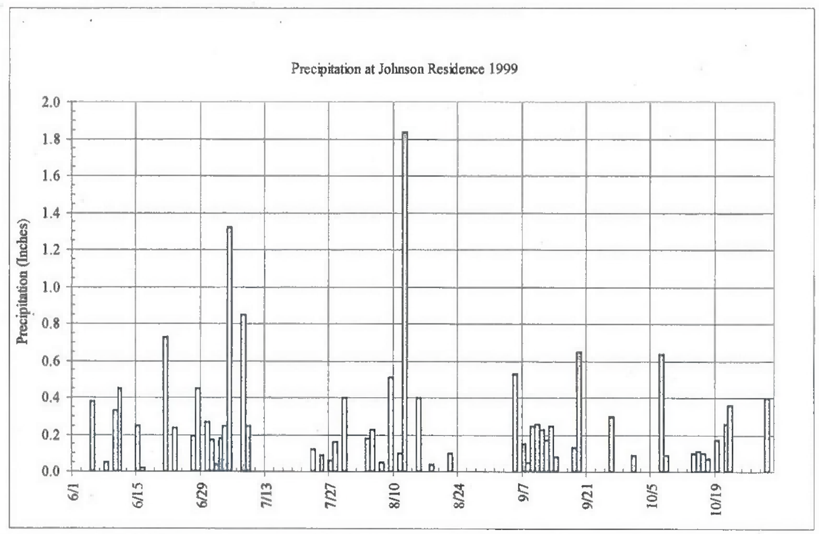


Figure A-12. Precipitation monitored at Johnson residence (Baraga, MI) in 1999.

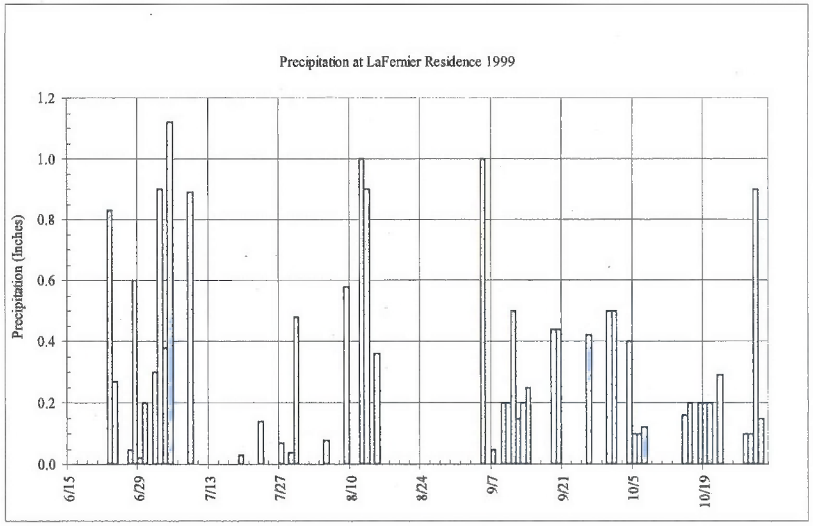


Figure A-13. Precipitation monitored at LaFernier residence (Baraga County, MI) in 1999.

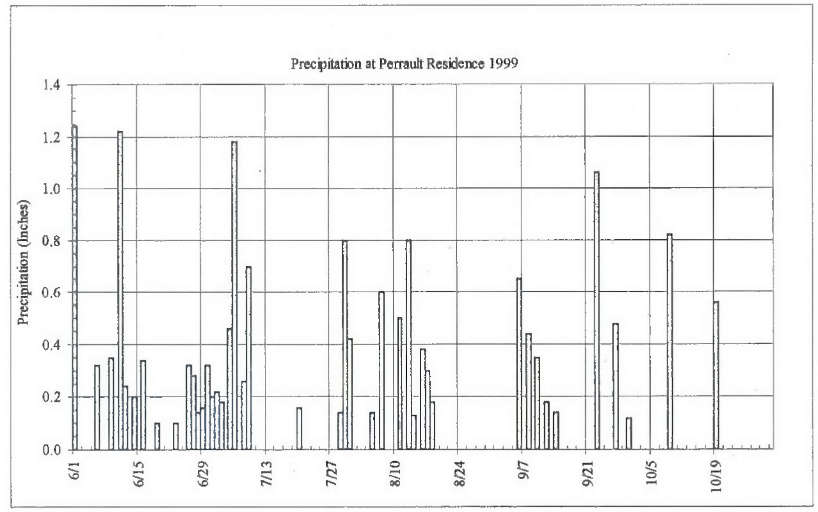


Figure A-15. Precipitation monitored at Perrault residence (Baraga County, MI) in 1999.

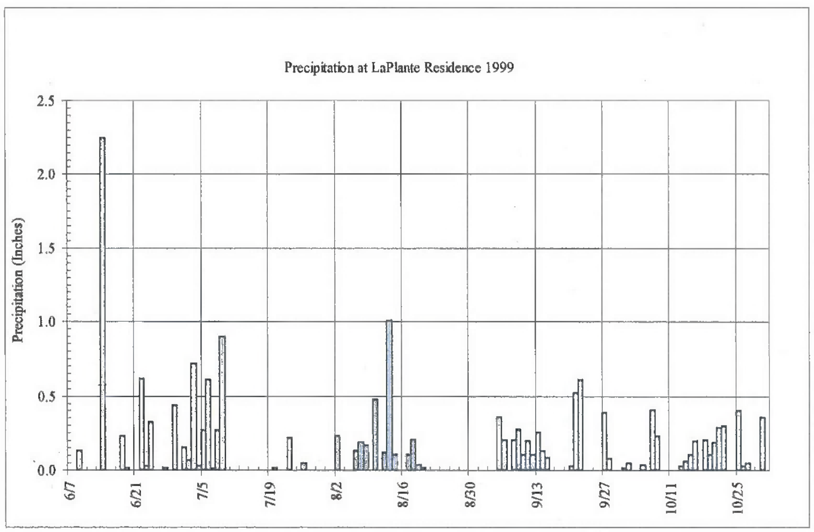


Figure A-14. Precipitation monitored at LaPlante residence (Baraga County, MI) in 1999.

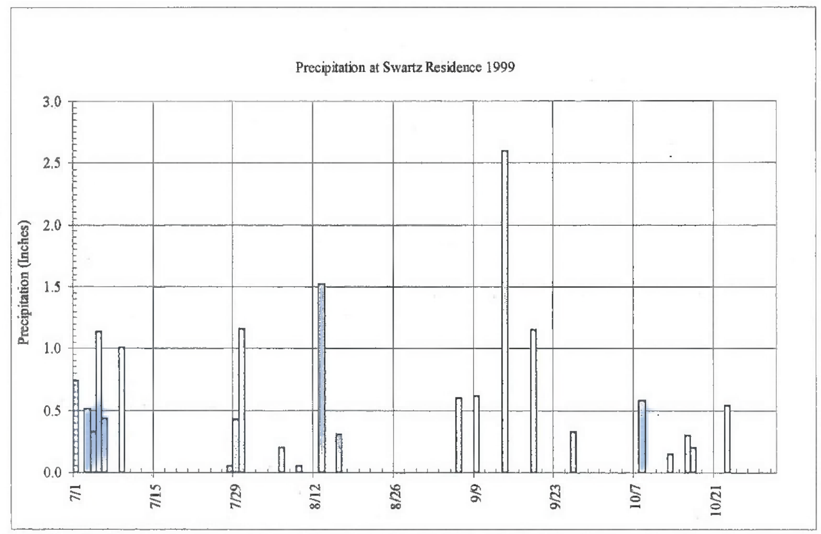


Figure A-16. Precipitation monitored at Swartz residence (Baraga County, MI) in 1999.

Appendix B. Daily temperatures at KBIC Fish Hatchery (Baraga County, MI)

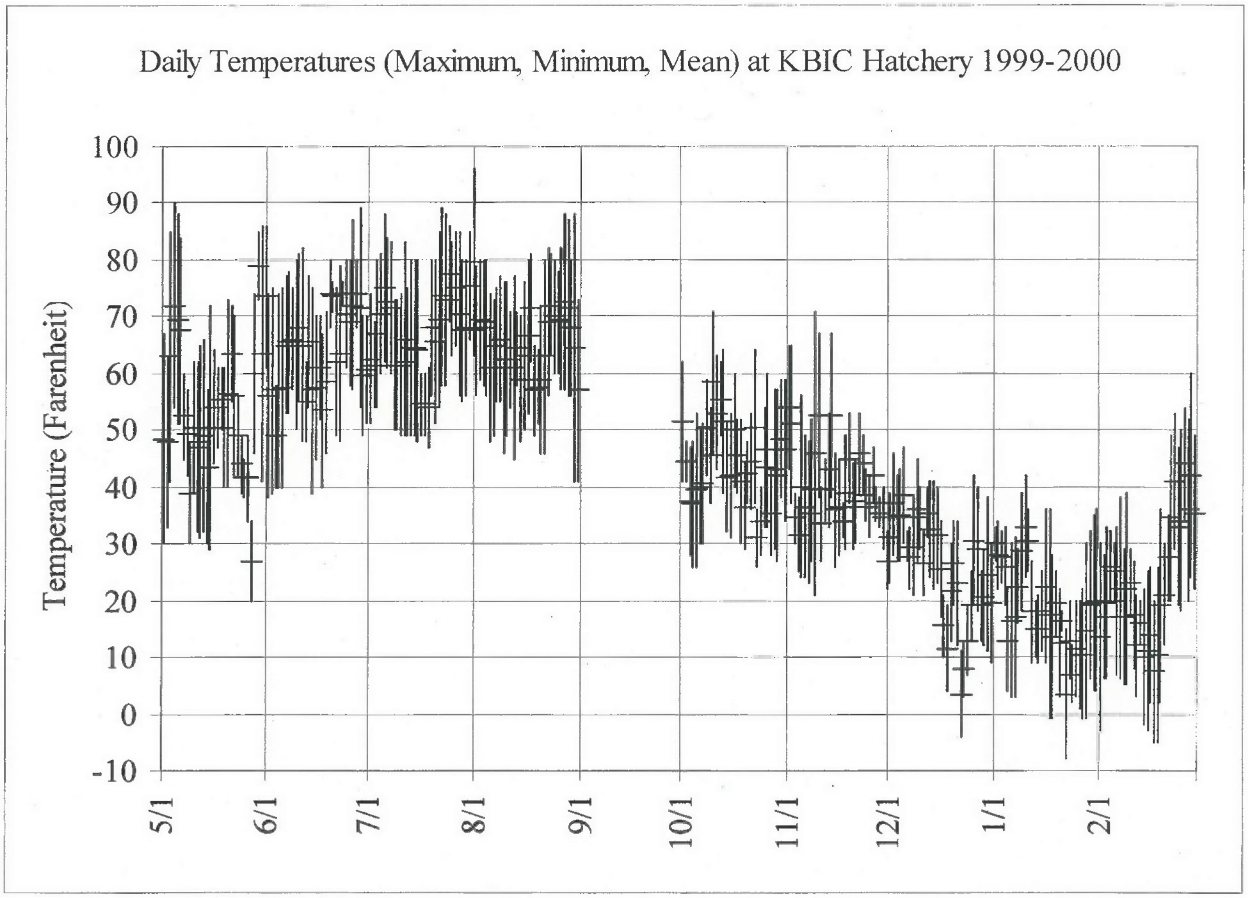


Figure B-1. Daily temperatures (maximum, minimum, and median) observed at the KBIC Fish Hatchery, May 1999 through February 2000.

26 February 1999

Daniel Cozza WS-15J
U.S. Environmental Protection Agency
77 West Jackson Blvd
Mail code WS-15J
Chicago, IL 60604-3507

Dear Mr Cozza:

Mary Manydeeds, BIA Hydrologist, contacted me today and requested our draft Unified Watershed Assessment Plan (attached). She also asked if we had any stream restoration projects, which I believe are your Clean Water Act Section 106 Grant Proposals. This reference stems from your January 29, 1999 letter to the Tribal Unified Watershed Assessment Preparers which unfortunately went to Bill Beaver and not me. As you can see on my August 1998 memo to Ms. Manydeeds, I prepared our tribal watershed plan. Considering the time element and my familiarity with the our local watersheds, I have written three projects:
We have biologically surveyed various watersheds within and adjacent to the L'Anse Indian Reservation in Baraga county, Michigan. We have consistently seen a problem with excessive sedimentation or stream embeddedness caused by poor stream crossings and poor land management. Stream embeddedness reduces available habitat for fish spawning, larval fish, and macroinvertebrates communities.
1) In 1997, we surveyed various index stations on the Little Carp River. Approximately 5 years prior to our survey, a heavy spring runoff had washed out the Beartown Road stream crossing on the Little Carp. This released 400 cubic yards of fine sediment into the river. This crossing is approximately 4 miles from the river mouth at Lake Superior. Also during this same time period, a beaver dam that created a two acre pond washed out releasing more fine sediments into the river. The stream crossing on the Beartown road was replaced, but no action was taken to remove the sediments from the stream. The beavers have been trapped from this site and have not rebuilt a dam. Last year with a low precipitation rate in this watershed, this sand deposition blocked the flow of this river into Lake Superior! <u>Prior to the above events, this river was utilized by Tribal members for exercising their treaty rights.</u> This heavy sedimentation load has stopped trout migration to the watershed and sediments have inundated the natural gravel spawning beds in the last half river mile of the Little Carp. We propose the following solutions and request U.S. Environmental Protection Agency funds to enhance this watershed:

a) We have shown these sites to Randy Wilkinson and Bruce Petersen of the USDA Natural Resource Conservation Service and asked for their assistance. In 1999, they'll work with NRCS engineering staff to quantify the sediments at the river mouth. Our rural location, 500 miles from Detroit and 400 miles from Chicago, precludes us from securing a sub-contractor with a portable dredge to remove these sediments. Therefore, Randy Wilkinson has researched purchasing a portable pumping system to assist us with this project. As documented in his 1/26/99 letter to me, he has found the equipment at a cost of $50-60,000 to purchase a portable pump. We propose to purchase this equipment with EPA funds and work with NRCS, Trout Unlimited, and a local sub-contractor to start a demonstration project on the Little Carp River to remove sediments and deposit the material at an upland site. All pertinent tribal, federal, and state permits will be received prior to the initiation of this project. A proven approach can also be utilize on other Reservation streams, and other Upper Peninsula sites.

b) A common approach utilized by the U.S. Forest Service and Michigan Department of Natural Resources in the Upper Peninsula is the creation and maintenance of sand traps in watersheds. A sub-contractor is hired to remove sediments with a backhoe excavator and create a deep hole in the river. Periodically as the hole fills with additional sediments, the backhoe is utilized to remove more sediments. The sediments are then removed to an upland site. We would work with the related agencies to find an appropriate site on the Little Carp river and hire a sub-contractor to create a sand or sediment trap. Back hoes operators and equipment can be rented at $75 / hour. A dump truck holds 8 cubic yards (or 1 load) and can be rented for $300/ day. Using 400 cubic yards of sediment, an 8 hour work day, and 2.5 loads of sand removed/ day. This contract would cost $18,000. Considering, the road crossing has been repaired and the beaver problem corrected, the Keweenaw Bay Indian Community believes most of the sediment load would be removed in 1 field season and the Community would commit to maintaining the site after the first year.

The difference in the two projects is owning the equipment and leasing it to other organizations for other streams or hiring sub-contractors and renting their equipment this year at the Little Carp and future years at additional sites.

2) Another project would address some of the poor stream crossings in L'Anse Reservation streams. Frequently, loggers and recreationalists simply cross a stream by driving their vehicle through the stream bed. These stream fords wear down stream banks and deposit more sediment into the stream. A load of gravel (4 cubic yards on each stream bank) and 2-3" in diameter raked on each bank would stabilize the banks and reduce sediment loads. The Michigan DNR has successfully utilized this approach on other streams. We are aware of 12 stream crossings that meet the above description. We propose to hire a sub-contractor to dump ½ load of gravel (4 cubic yards) on each stream bank and spread it out. 8 cubic yards of gravel delivered to a site would cost $150/ load. A bull dozer would take 2 hour at each site to spread the gravel ($75/ hour). Therefore, each site would cost $300 for a total cost of $3,600 to stabilize stream banks at 12 stream crossings.

We don't have time to obtain final budgets for any of these projects, but NRCS and our staff would match in-kind with time spent on these projects. Trout Unlimited might also contribute funds towards these projects. If given additional time, I could refine our requests. Please contact me should you have additional questions at 906-524-5757 or email mdonofri@up.net. Thanks for giving us the opportunity to submit this proposal.

Sincerely

Michael Donofrio
Biological Services

C: Amy St Arnold, Asst CEO
Mary Manydeeds, BIA/ MAO
DRAFT Clean Water Action Plan/ Unified Watershed Assessment DRAFT

Introduction-
The Keweenaw Bay Indian Community is signatory to the Treaty of 1842 and 1854 which reserve gathering rights in Minnesota, Wisconsin, and Michigan. The Community considers the western Upper Peninsula as their home territory and mostly exercise their treaty rights from the Ontonagon River to the Chocolay River in Michigan's western Upper Peninsula. Our tribal members hunt, fish, and gather in Wisconsin and Minnesota, but we'll defer those watershed assessments to the respective tribes of those regions.

Assessment-
The following is a brief description and justification for the Unified Watershed Assessment prepared for the Keweenaw Bay Indian Community:

1) Black Presque Isle- 04020101: These watersheds lie mostly within the Ottawa National Forest and Porcupine Mountains State Park and entirely within the 1842 treaty ceded territory. These rivers are listed as federal wild and scenic rivers which offers a great deal of protection, but extensive logging is still practiced in these watersheds. Bald eagle, osprey, gray wolf, and trumpeter swan exist in these watersheds. We are aware of problems in this USGS hydrologic unit based on long standing concerns.

2) Ontonagon- 04020102: This watershed also lies within the Ottawa National Forest and entirely within the 1842 treaty ceded territory. This river system is also list as federal wild and scenic rivers. Extensive copper mining, intensive logging, and hydroelectric dams are present in this system. The mouth of the Ontonagon river has experienced development from a marina, paper mill, drainage of wetlands, and bridge crossings. At least four endangered species exist in this watershed: trumpeter swan, bald eagle, gray wolf and lake sturgeon. The site of the present paper mill and marina were the location for a historic Ojibwa village. We're working with Michigan to restore the threatened species lake sturgeon to this system. Wild rice is also harvested in this watershed. We know of problems in this USGS hydrologic unit stem from our intervention status in a Federal Energy Regulatory Commission (FERC) re-licensing project and relevant issues. We have also performed some lake sturgeon assessments in this river.

3) Keweenaw Peninsula- 04020103: The peninsula is composed of many small watersheds and littered with several abandoned copper mines. Some of this region was recently designated as a federal historic park, but very little land is owned for this purpose. Land values are skyrocketing and development abounds in this region. An EPA superfund site, Torch Lake, also exists in this watershed. Extensive logging is also occurring in this region which is leading to erosion problems. The treaty of 1842 and subsequent mining activity forced the abandonment of several Ojibwa communities in this region. We are aware of problems in this USGS hydrologic unit based on long standing concerns.

4) Sturgeon- 04020104: The eastern portion of this watershed lies within the L'Anse Indian Reservation. A hydroelectric dam exists on this river. Extensive logging occurs within this watershed which is causing erosion, embeddedness and turbidity in the system. At least four endangered species exist in this watershed: trumpeter swan, bald eagle, gray wolf and lake sturgeon, as well as the Kirkland warbler. The city of Chassell has their waste treatment in this

watershed and the state of Michigan owns a wetlands preserve in this system. The Sturgeon river is also listed as a federal wild and scenic river. We know of problems in this USGS hydrologic unit based on our involvement in a FERC re-licensing project and personal observations.

5) Dead Kelsey- 04020105: Most of the L'Anse Indian Reservation lies within these watersheds. Industrial development is evident through utility plants in L'Anse and Marquette and Celotex Corporation plant in L'Anse. Cleveland Cliffs Inc owns and operates extensive iron mines in the southern half of this watershed as well as several other abandoned mines. At least four endangered species exist in this watershed: trumpeter swan, bald eagle, gray wolf and lake sturgeon. Extensive logging occurs throughout this region with the same problems mentioned above. Hydroelectric dams occur on the Dead river. Several communities have waste treatment facilities in this area including Baraga, L'Anse, Big Bay, and Marquette. The Yellow Dog river is listed as a federal wild river. We are aware of problems in this USGS hydrologic unit from our biological assessments of the Kelsey Creek, Little Carp River, Hazel Creek, Menge Creek, Black Creek, Boyers Creek, 9 stations on the Falls River, 10 stations on the Silver River, and Little Silver Creek. We are also involved in FERC re-licensing efforts on the Dead River.

6) Betsy Chocolay- 04020201: The Chocolay river serves as the eastern boundary of the treaty of 1842. Tribal members from the Marquette area exercise their treaty rights in this region. The Chocolay river is under restoration through a community accepted watershed plan. At least four endangered species exist in this watershed: trumpeter swan, bald eagle, gray wolf and lake sturgeon. Extensive logging also exists in these watershed which is leading to erosion problems. We know of problems in this USGS hydrologic unit from long standing concerns and NRCS watershed planners on the Chocolay river.

7) Lake Superior- 04020300: Lake Superior is influenced by industrial development along it's shores, contaminant emissions, and sedimentation at its river mouths. Tribal members are commercially fishing it's waters. Tribal members are unable to harvest some fish species due to contaminant levels. At least four endangered species exist in this watershed: trumpeter swan, bald eagle, gray wolf and lake sturgeon. We know of problems in this watershed from direct experience in professionally assessing the fishery and associated habitat over the last 11 years. We are also members of Great Lakes Fishery Commission and Great Lakes Indian Fish and Wildlife Commission committees which focus on Lake Superior.

Our Future Involvement-

We'll complete our biological surveys of the major watersheds in Baraga county in 1999, except the Sturgeon, Little Huron and Huron rivers which are assessed by the Michigan Department of Natural Resources. We have established index stations and we'll go back to each site and perform another survey every 4-5 years. We'll document any improvements or degradation, seek funding to correct problems and work with other agencies and private landowners where necessary. Our involvement in various professional committees will keep us update on other watersheds, including the re-licensing of FERC hydroelectric dams.

We're currently working to develop a federally recognized Tribal Conservation District in Baraga county and once established might extend that district to adjacent counties. We are committed to working with private landowners and other agencies to improve the environment. That fact is further evidenced by our partnership with several organizations to protect wetlands and associated habitats through a $1 million North American Wetlands Conservation Act grant application filed in April of 1999. These organization include: MIDNR, MDEQ, USFWS, NRCS, MSU Extension, Bay Mills Indian Community, The Nature Conservancy, The National Forest Service, The National Park Service, and Ducks Unlimited.

We perceive this document as a working draft and we'll continue to update it as time and personnel become available to refine our knowledge of these watersheds of concern.

Modeling of the Silver River Watershed

Angela Quillo
Doug Moore
Jeff Thompson
Lindsay Bussell
Ben Drenth

Executive Summary

Keweenaw Bay Indian Community (KBIC) has hired the Aqua Terra Tech Enterprise team to study the groundwater resources of the L'Anse region of Baraga County. As part of this study, Aqua Terra Tech is currently working on developing a model of the hydrogeology of the lower Silver River watershed. The phases involved in creating and running the model were to define the boundary of the watershed, collect applicable data for the model with respect to hyrdrogeologic and hydraulic conditions, to create a conceptual model, then finally transform the conceptual model into a numeric model by assigning parameters obtained through various processes. A conceptual model was created, and a first attempt at a numeric model was undertaken. Unfortunately, a lack of data in some areas resulted in some undesirable effects and hindered the model's capability to work. At the present time, a 2-layer model is nearly ready to run simulations, but much refinement will be necessary to make this model accurate and comprehensive. It is believed that with additional data collection in the fall of 2002 that a good working model of the lower portion of the Silver River watershed will be created.

Acknowledgements

This project was done under the guidance of J. S. Gierke, Associate Professor of Geological and Environmental Engineering, Department of Geological Engineering and Sciences, Michigan Technological University. We acknowledge the financial and other support provided by the Natural Resources Department of the Keweenaw Bay Indian Community. Specifically, we would like to thank Micah Petoskey, water quality specialist, and Michael Donofrio, tribal natural resources director, and Mike Duschene, formerly water quality specialist for their work and logistical support. This project is part of Aqua Terra Tech within Michigan Technological University's Enterprise program

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1 Introduction

1.1 Background

Keweenaw Bay Indian Community (KBIC) has hired the Aqua Terra Tech Enterprise team to study the groundwater resources of the L'Anse region of Baraga County. As part of this study, Aqua Terra Tech is currently working on developing a model of the hydrogeology of the lower Silver River watershed (Figure 1). This portion of the Silver River watershed is about 14 square miles in size and consists of rural, forested land. Geologically, the watershed is composed of thin glacial till overlying metamorphic rocks and sandstone. The Silver River itself is located in the central portion of its lower watershed and is fed by numerous small streams.

The data used to create the model has come from published well logs, geophysical surveys, and pump tests. This report discusses how the model was developed, from the collection of field data to the compilation and processing of that data, and then discusses the model itself.

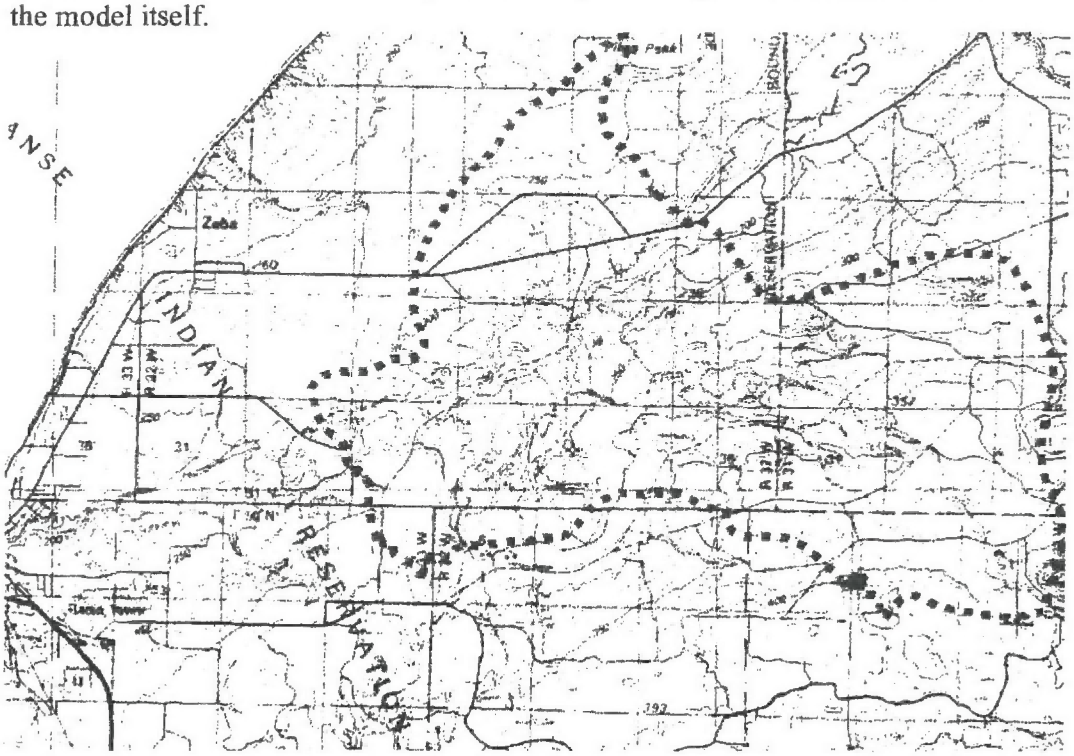

Figure 1: Location map of lower Silver River watershed, outlined in blue.

1.2 Previous work

A preliminary GMS model in the Little Silver River (Zeba Creek) was generated last year. This project was also part of the Aqua Terra Tech Enterprise. The information obtained from their progress was used as a guide for the formation of the Lower Silver

River watershed model. Much of the data used in creating the Lower Silver River model was collected in the fall of 2001 by the Aqua Terra Tech Enterprise program.

2 Objectives and Scope

2.1 Objectives

Eight major tasks were defined for the project. These were to prepare geological cross-sections, analyze pump test data to determine transmissivities, review geophysical data and well logs, contour bedrock topography and water table topography, delineate the river course and elevation, develop a model to simulate annual flows and steady state conditions, attempt to simulate monthly conditions for the calendar year 2000, and evaluate the sensitivity of the model to grid resolution. Several of these initial tasks were either altered or redefined as the project progressed. The modeling was simplified into a conceptual model and creation of a numerical model for later simulations.

2.2 Scope

Data collection was limited to areas with good roads or in locations where people have a well. Well log information was present for most, but not all of the wells. The exact location of many of the wells was not known; the best information for the location was a portion of a section and the position of the wells for use in the model was determined using a topographic map and Digital Elevation Model (DEM) data.

3 Approach

3.1 Data Collection

3.1.1 Surface Information

Data collection from the surficial group included constructing geological maps, locating wells and determining land use and vegetation for the Silver River watershed. The group consisted of five individuals who divided these important tasks among themselves. Joseph Kraft and Jacob Lobremeier were the key individuals who performed the field reconnaissance of the watershed area. These individuals divided the watershed into sectors A through F and completed the reconnaissance in two intense mapping sessions. The first mapping session (sectors A & B) occurred in the north section and "the main features mapped were the lower Silver River channel and basin, the oxbow lake (unnamed), the northwest intermittent tributary, Kallio Creek, the overland mapping along Skanee Road and the overland hillside regions" (Kraft, 2001). The second major mapping session (sectors C-F) occurred in the southern and western sections and "the major features mapped included the upper parts of the Silver River channel and basin, Silver River Falls, the Third Lake area, the Bella Lake area, Dakota Creek, Commanche Creek, Page Creek and the overland hillside and marsh areas to the east and west of the river" (Kraft, 2001).

The three remaining individuals, Mellisa Le, Jessica Tuomi and Angela Quillo, worked to locate wells in the watershed. Well logs from the area provided the township and range of wells. This information was used in conjunction with a topographic map to locate wells. Some wells were visited on-site and a Trimble Global Positioning System (GPS) unit was used to ascertain the Universal Transverse Mercator (UTM) coordinates for the wells. The overall results of the surficial group can be recorded in the *Surface Study Report: Silver River Watershed (Lower).*

3.1.2 Bedrock information:

In order to determine the subsurface geology, several methods were employed. The first source of information was well logs provided by the Keweenaw Bay Indian Community and the Baraga County Health Department. These give information on the stratigraphy and static water level for a water well. Some seismic refraction surveys were also available. These surveys were used to determine the thickness of the unsaturated and saturated glacial till and the depth to the bedrock. Field mapping by the Surface group in the fall of 2001 provided information about bedrock outcrops. Finally a geologic map was used for comparison and to give a better idea of the underlying geology.

Well logs are an excellent source of information about the geology of an area. The well logs contain a general location in terms of portion of a section and a verbal description or schematic map. The importance of well logs is that they contain stratigraphic information, in terms of depth and thickness of each geologic unit and the lithology. In order to determine the location of the well for modeling purposes, UTM easting and northing were determined by using either topozone.com or the Digital Elevation Model (DEM) with NAD27 as the datum. Elevation data were determined using the DEM data.

The bedrock group completed seismic refraction surveys in the fall of 2001. A total of 18 seismic surveys were done in various areas of the watershed. Descriptions of survey technique and results are presented by Decleene et al (2001). In addition, GPS coordinates were obtained at the survey locations.

The final two sources included data from the Surface group and a geologic map. Outcrop data collected by the Surface group in the fall of 2001 were used (Kraft et al, 2001). The UTM location and elevation of these data were determined using DEM data. Finally, a geological map (Figure 2) provided information on the distribution of the geological units. This map was used to show the distribution of bedrock types and used to indicate where better delineation of units is required.

Once the bedrock information was gathered and organized, it was put into GMS with the borehole editor and then made into geologic units. This procedure is discussed in the TINs to Solids modeling section later on. Once this was done, geological cross-sections were generated and a diagram of cross-sections was created using GMS.

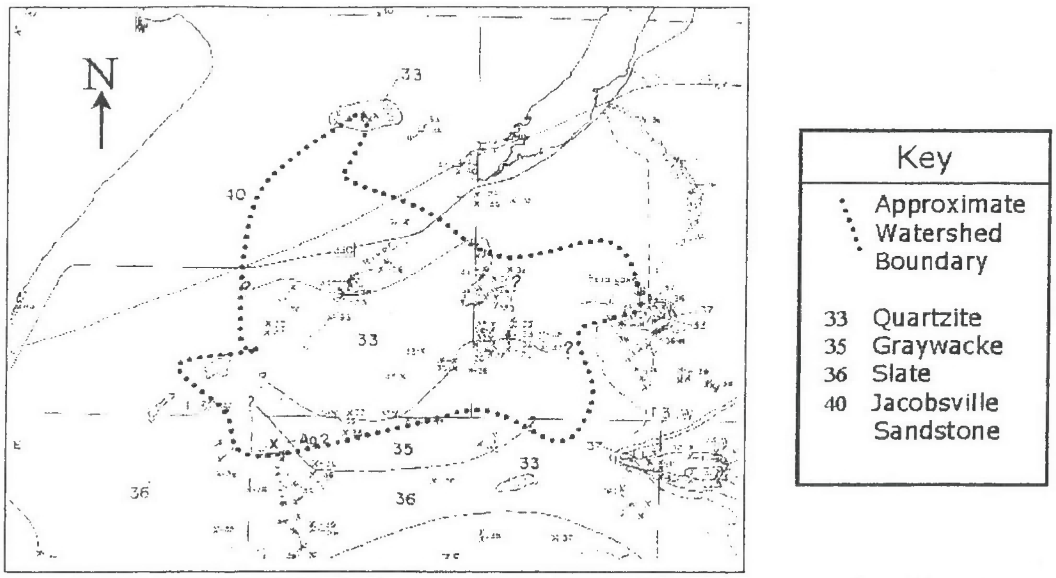

Figure 2: Generalized Geologic map of the Lower Silver River area (modified from Bodwell 1972).

3.1.3 Aquifer properties from pumptest

The pumptest data was modeled using GMS software. First, the data collected by Dr. Gierke was analyzed. The drawdown curves, including pump-down and recovery, were plotted on a graph. A grid was created in GMS by incorporating the parameters of the pump test. Initially, values for hydraulic conductivity and specific yield were estimated and entered into GMS. After the appropriate parameters were entered, MODFLOW was run in GMS and the output file was examined. Drawdown values and their corresponding times from the output file were plotted, creating a model drawdown curve. This model drawdown curve was compared to the observed drawdown curve from the pump test data. This was done for the recovery periods as well. Values for hydraulic conductivity and specific yield were subsequently changed to match the model curve to the observed curve. The values corresponding to the model curve that most accurately matches the observed curve were retained. A complete pump test report can be found in John S. Gierke's Interim Report on a Pumptest at the Leo Niemala Residence, Silver River Watershed, Baraga County, Michigan, 2002.

3.2 Computer Modeling with Groundwater Modeling System (GMS) and MODFLOW

3.2.1 Conceptual Model of the Lower Silver River Watershed

Groundwater Modeling System (GMS) was used in designing a conceptual model of the Lower Silver River Watershed. The conceptual model uses a 3-D grid approach to model the watershed. Different coverages can be used to apply necessary parameters for different aspects of the model. Parameters such as hydraulic conductivity, transmissivity, and specific yield are applied to each block of the 3-D grid once the model is complete. A

MODFLOW simulation is run once the model is concluded and may be altered for desired outcomes. The MODFLOW simulations allows the head contours, water table and flow budget to be viewed using GMS as well.

Modeling began with importing a background image of the Lower Silver River Watershed. The background image consisted of a topography acquired from topozone.com. Sources/sinks, layer 1, layer 2 and recharge coverages were then created by applying special properties to each coverage. The sources/sink coverage includes the delineated river, drains and constant head lakes as well as the conductance of the streams. Layer 1 and layer 2 coverages include vertical and horizontal hydraulic conductivities, specific yield and storage and conductance. The recharge coverage includes the recharge value. All of the coverages include the watershed boundaries and a three-dimensional grid as well.

3.2.2 TIN to Solids Modeling

In order to create a more accurate model, the compiled information from the well logs, seismic surveys, and outcrop data were input into a borehole file. In order to aid in the creation of a borehole file for GMS, a spreadsheet format was used for data input. This spreadsheet was then converted to a borehole file for use in GMS. The borehole file requires units to be numbered and thickness of each unit reported. For modeling purposes in the Lower Silver River watershed, four main units were used. These are glacial deposits, sandstone, slate, and quartzite. Other unusual occurrences as noted on well logs were also put into the borehole file, although they may not be used in the model creation. Once the borehole file was created, the borehole module of GMS was used to pick unit contacts and these contacts were made into triangular irregular networks (TINs). TINs were made for the ground surface, the base of the glacial drift, the top and bottom of the sandstone, and for the top of the slate and quartzite. For the purposes of the initial model, the slate and quartzite were grouped together due to the limited amount of well data for the distribution of quartzite and the fact that these two units have more similar properties as compared to the sandstone or the glacial deposits. Once the TINs were created, they were used to create solids. The solids that were created were the glacial drift, sandstone, and slate, which included quartzite. The use of these solids in the model will be discussed later.

3.2.3 Numerical Modeling

Parameters based on data and observation were used to define the coverages. A three dimensional grid was constructed with 528 ft east-west by 528 ft north-south and the third dimension varried. With the completion of the TIN to solid method, MODFLOW simulations will be performed for the watershed.

4 Experimental Results and Discussion

4.1 Initial results

4.1.1 Cross-sections

The compiled bedrock data was used to generate several cross-sections and a diagram of multiple interconnected cross-sections. Figures 3a through 3c are cross-sections and Figure 3d is a diagram of cross-sections. Figure 3a is an east-west cross-section at the south end of the watershed, Figure 3b is an east-west cross-section at the north end of the watershed near Ford Farm Road, Figure 3c is a north-south cross-section from near Pinery Road to north of Ford Farm Road. Due to limited well log data with quartzite, the Slate and Quartzite were left together since they are both metamorphic rocks, they are part of the same formation and they have more similar hydrologic characteristics than the sandstone or glacial drift. However, the Quartzite will most likely have a lower hydraulic conductivity.

Figure 3a shows that there is a thin glacial drift (black) overlying slate and quartzite (yellow). This glacial drift is thicker at the east side of the cross-section. Figure 3b shows Jacobsville sandstone overlying the slate/quartzite with a thin layer of Glacial drift over everything. An artifact of the creation of the solids is shown where the Jacobville sandstone appears to be above the glacial drift. Figure 3c indicates an area where the glacial drift is substantially thicker than other areas. This is near the Third Lake area and is confirmed by well log data. Figure 3d shows an oblique view of several cross-sections.

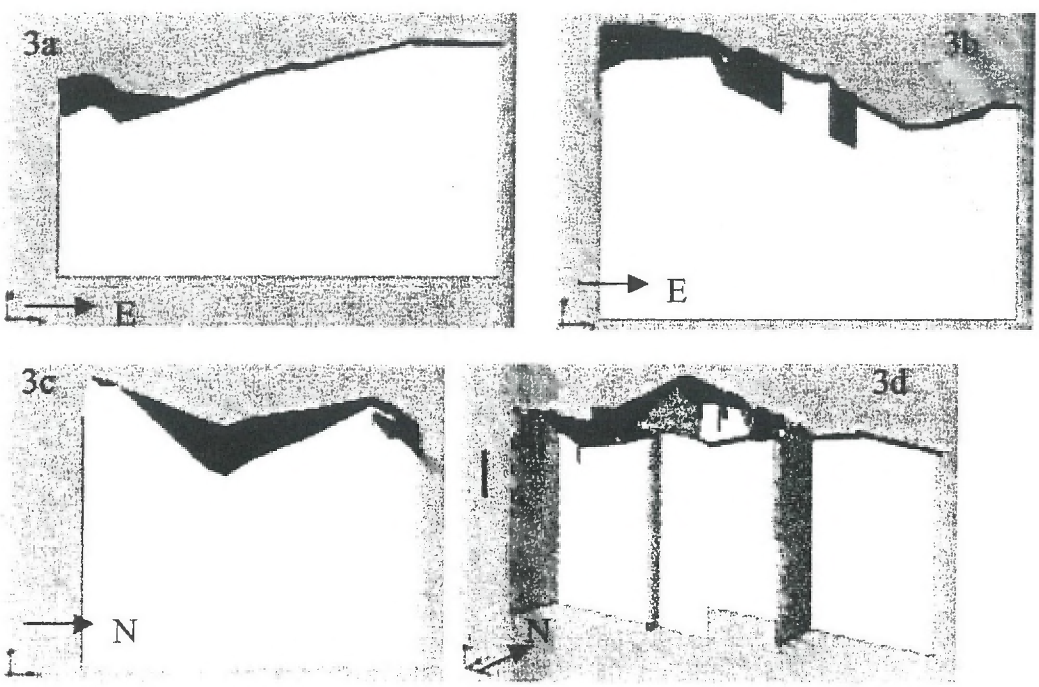

Figure 3: Cross-sections (a-c) and a geologic fence diagram (d) of the Lower Silver River watershed area. Black is glacial drift, Red is Jacobsville Sandstone, and Yellow is slate and quartzite.

4.1.2 Bedrock topography

The bedrock topography was contoured using GMS. The result is shown in Figure 4. Due to the area of sparse data in the central region of the watershed, the data in this region are suspect. In the southeast, southwest, and north (except for Pikes Peak) the results are what would be expected.

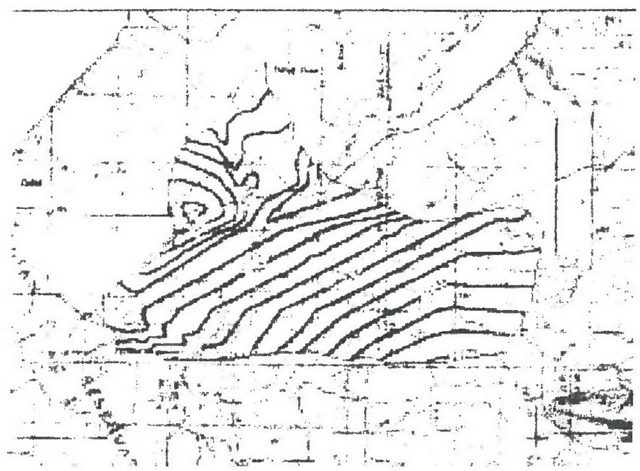

Figure 4: Bedrock Topography map. Contours of elevation of bedrock in feet above mean sea level.

4.1.3 Aquifer Properties

Figure 5 shows the plot containing the observed curves versus model curves. The corresponding values for hydraulic conductivity is 2.31E-03 ft/s and specific yield is 0.01. The model curves do not match up exactly with the observed curves, but they are reasonable. The large diameter of the well has a large effect on the drawdown values, and this was not completely accounted for. Due to this fact, the correlation of data at later near the end of the pumptest was emphasized instead of the early time data.

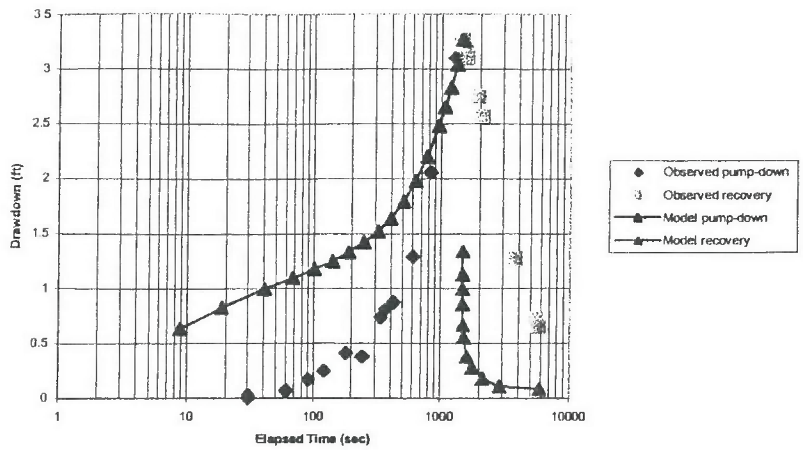

Figure 5: Plot showing observed and model drawdown curves.

4.2 Model results

4.2.1 Conceptual Model of the Lower Silver River Watershed

The conceptual model defined the watershed and its properties for use in MODFLOW simulations. Figure 6 defines the watershed as completed with the conceptual model. The black outlines the watershed boundary, the blue line represents the river, the green lines correspond to drains (intermittent streams), and the two smaller black outlined areas correspond to lakes with constant head.

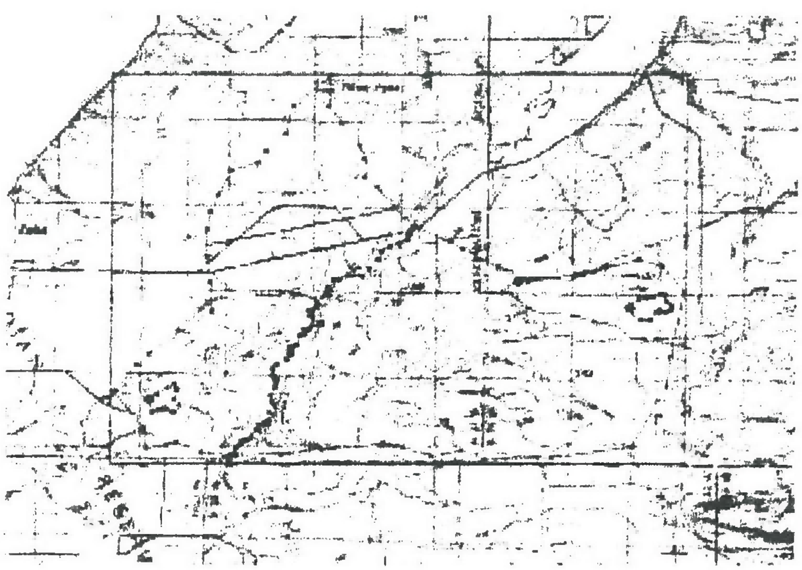

Figure 6: Watershed boundaries with the delineated Silver River (blue), drains (green) and constant head lakes (black).

4.2.2 Numerical Model of the Lower Silver River Watershed

Parameters used in the numerical model are defined in Table 1 in Appendix A. A two-layer model was created with the first glacial drift and the second layer bedrock. A grid was constructed with 528 ft by 528 ft individual cells. To better define the subsurface geology, borehole data was implemented and used in GMS. With the completion of the TIN to solid method, MODFLOW simulations will be performed for the watershed.

5.0 Conclusions

Several areas of the model have much data while other areas have none. The conceptual model is nearly complete, but the numerical model needs much refinement for an accurate simulation to be attempted. An attempt at a steady state simulation was made, but the river and drain elevations were located beneath the first layer, so the model would not run. If these could be corrected, then a first approximation using the model could be attempted. Due to time constraints, the tasks of running simulations and testing grid sensitivity were not accomplished.

6.0 Recommendations

Despite the progress made on the model this year, one major problem is limiting its effectiveness and reliability to produce quality predictions: the model contains large central region where no bedrock or water table depths are known. The interpolation between points resulted in unrealistic scenarios. Correcting such errors is time-consuming and difficult.

For the refinement of the model, a three-layer model may be more effective due to the fact that the north end of the watershed contains wells that penetrate glacial till, sandstone, and slate. For the simulations to occur, the elevations of the river and stream need to be redefined since they are based on the DEM data which is of higher resolution than what is possible to obtain for the bedrock and glacial till. This causes the rivers and drains appear to be subterranean in many places.

Next year, more data needs to be collected, particularly in the central and eastern sections of the sub-watershed. As a general rule, any area that is not populated and does not have roads is extremely limited in the amount of existing data. Collecting data from these areas will probably require a higher ground clearance vehicle, preferably with 4-wheel drive. In addition, the data needs to be more evenly spaced instead of the concentrations of points that currently exist. This is to maximize the effectiveness of the data collection process and make accurate contouring easier. The first areas to concentrate on obtaining more data are on the road that connects Pinery Road to Skanee Road and the two tracks and roads in the Mead Paper on the east side of Silver River.

Finally, when this field data collection takes place next fall, a few procedures will make the process flow much more smoothly and prevent some of this year's pitfalls that wasted time. These procedures are outlined by Drenth (2002). Also, it is important that the same datum be used for every survey and the modeling aspect. Using an incorrect datum places the coordinates in the wrong place. In the fall of 2002, the North American Datum 1927 (NAD 27) should be used because the digital elevation data provided was in NAD 27 format.

7.0 References

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8 Appendix: Coverage Parameters

Table 1.- Coverage Parameters

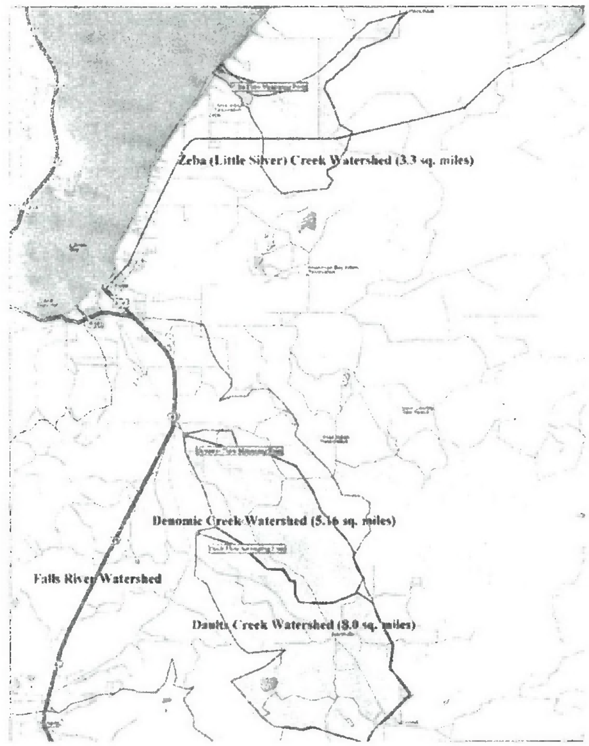
Sources/Sinks Coverage	
River Conductance	10,000(ft^2/d)/ft
Drain Conductance	500 (ft^2/d)/ft
Northern River Elevation	635 ft
Southern River Elevation	772 ft
Eastern Drain Elevations	998 ft
Western Drain Elevation	814 ft
Bella Lake Elevation	997ft
Third Lake Elevation	840 ft

Layer 1 Coverage	
Horizontal Hydraulic Conductivity	39.372 ft/d
Vertical Hydraulic Conductivity	39.372 ft/d
Specific Storage	1.0*10^-7 1/ft
Specific Yield	0.05

Layer 2 Coverage	
Horizontal Hydraulic Conductivity	0.0028 ft/d
Vertical Hydraulic Conductivity	0.0028 ft/d
Specific Storage	1.0*10^-7 1/ft
Specific Yield	0.01
Bottom Elevation	500 ft

Recharge Coverage	
Recharge	0.06 ft/d

Technical Report on Hydrology, Geology, and Hydrogeology of: Zeba (Little Silver) Creek, Denomie Creek, and Daults Creek Watersheds



Data Collected by Keweenaw Bay Indian Community Staff and Resident Volunteers

Monitoring Period: May 1999-February 2000

Data Compiled and Interpreted by

John S. Gierke, Ph.D., P.E., 22220 Broemer Road, Chassell, MI 49916

In partial fulfillment of Bureau of Indian Affairs **Aquifer Agreement No. AGF5099001**

Original Report Submitted: 29 December 2000

Summary

Precipitation, stream flow and water chemistry data were collected in three watersheds. Geological information from previous studies and well logs were compiled for the watersheds to characterize the hydrogeological setting. Evapotranspiration rates were estimated based on water budget analysis and independently using monthly temperature and precipitation measurements. Most of the annual precipitation is returned to the atmosphere via evapotranspiration. Annual runoff is only a small percentage of the annual watershed precipitation. More frequent stream flow monitoring is needed to improve the precision of the water budget analyses. Water quality parameters and water table elevations should be monitored at least annually to observe the impacts of changes to the watersheds on water quality and stream flows.

Introduction

Proper management of water resources for sustainable use and protection of water quality requires quantitative knowledge of various components of the hydrologic cycle (precipitation, evapotranspiration, runoff, etc.) and the watershed conditions (area, land use, etc.) and hydrogeological setting (subsurface geology, geochemistry, etc.). Development of quantitative assessments of the hydrological conditions requires field measurements and monitoring of stream flows, precipitation, groundwater levels, and water chemistry. While many of the needed measurements are based on well-established techniques, their applications to particular watersheds and climatic conditions will depend on factors that are regionally specific and maybe specific to a particular location if conditions are unique in terms of the terrain or land use. Therefore, a comprehensive monitoring plan should be flexible and adaptable to local conditions.

The Keweenaw Bay Indian Community (KBIC) has begun to develop comprehensive monitoring and assessments of their water resources, including both surface water and groundwater. Precipitation, stream runoff and chemistry, and subsurface geology were selected as the starting conditions and properties for long-term study. Rather than attempt to monitor all streams and characterize the geology/hydrogeology of the entire Tribal lands, two areas were selected for this preliminary assessment. Smaller watersheds were selected in this first effort to evaluate watershed hydrology, including the subsurface hydrogeology. Zeba (Little Silver) Creek Watershed in Baraga County exists as a single system that discharges directly to Lake Superior (Figure 1). Denomie Creek and Daults Creek are tributaries of the Falls River, and they exist as adjacent watersheds that drain the areas around the community of Herman in Baraga County (Figure 1). Precipitation monitoring was undertaken for the entire reservation by volunteers, mostly tribal residents and one agency (Copper Country Mental Health) and the KBIC Tribal Fish Hatchery. This report is a compilation of the measurements that were obtained during the project period of 1999 and estimates of the hydrology of the Zeba Creek Watershed and the combination of Daults and Denomie Creek Watersheds.

Study Objectives

The overall goal of this study was to gather baseline data on precipitation, stream flows, subsurface geology, and water chemistry for three small, relatively undeveloped watersheds within Tribal lands for the Keweenaw Bay Indian Community. This data was gathered for the following purposes for each watershed:

1. Estimate water budgets

2. Evaluate sampling frequency (areally and temporally) for future monitoring

3. Evaluate the utility of the data for tracking changes in water quality

4. Determine additional data needs and analyses for continued and future monitoring efforts.

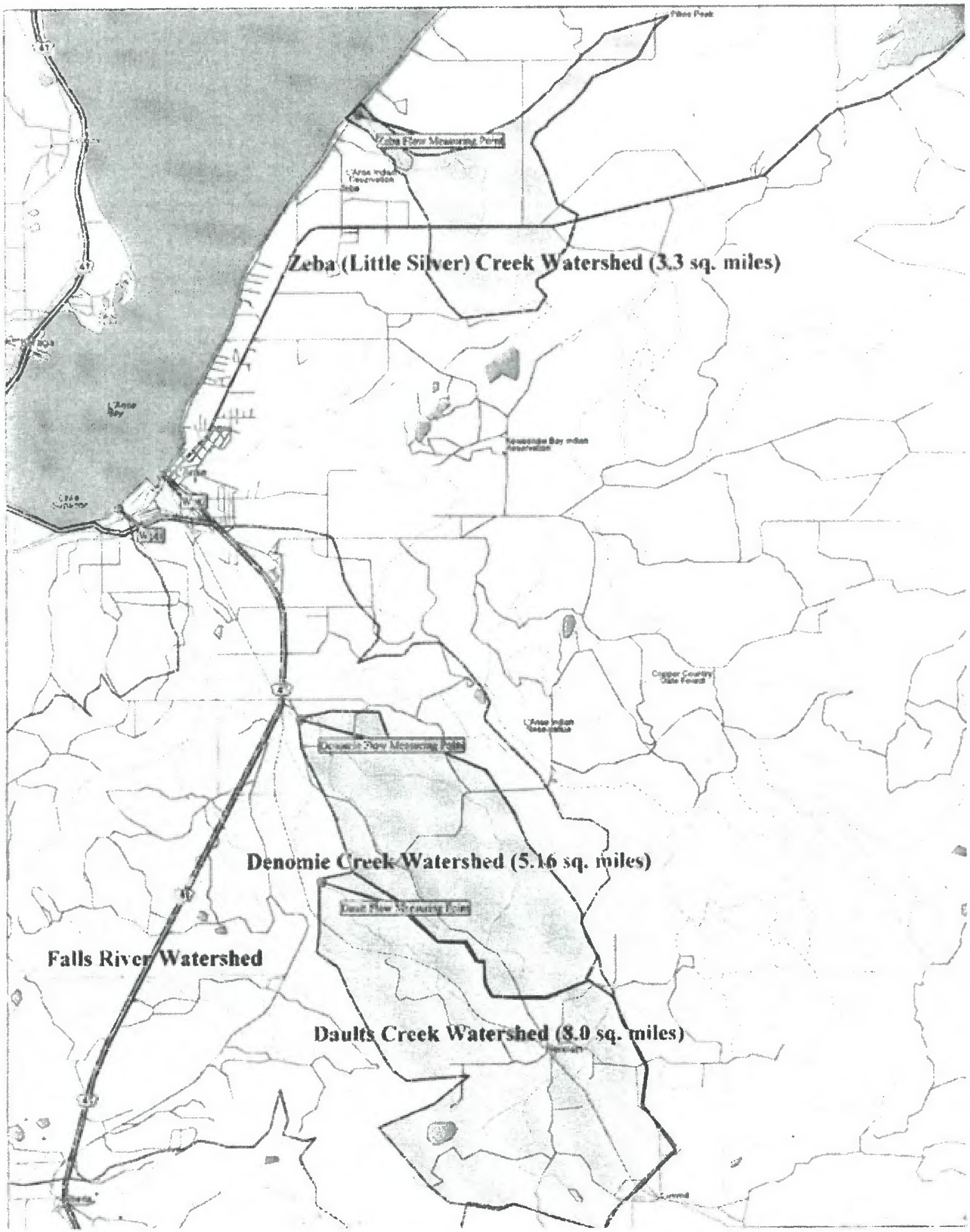


Figure 1. Map showing interpreted watershed boundaries based on USGS topographic contours.

Monitoring

Precipitation

Rain gages were distributed to volunteer residents with a request that they monitor precipitation on a daily basis, starting in May 1999 and continuing through the fall until snow season. The locations of the 16 rain gage locations are labeled in Figure 2 according to the last name of the resident or the name of the agency (Copper Country Mental Health, KBIC Fish Hatchery) that was responsible for the monitoring. Raw data from each location was collected by KBIC staff and put into an Excel spreadsheet. The data was organized by location and date and charts of the results are given in Appendix A. Table 1 is a summary of the observations in terms of the average and peak precipitation events.

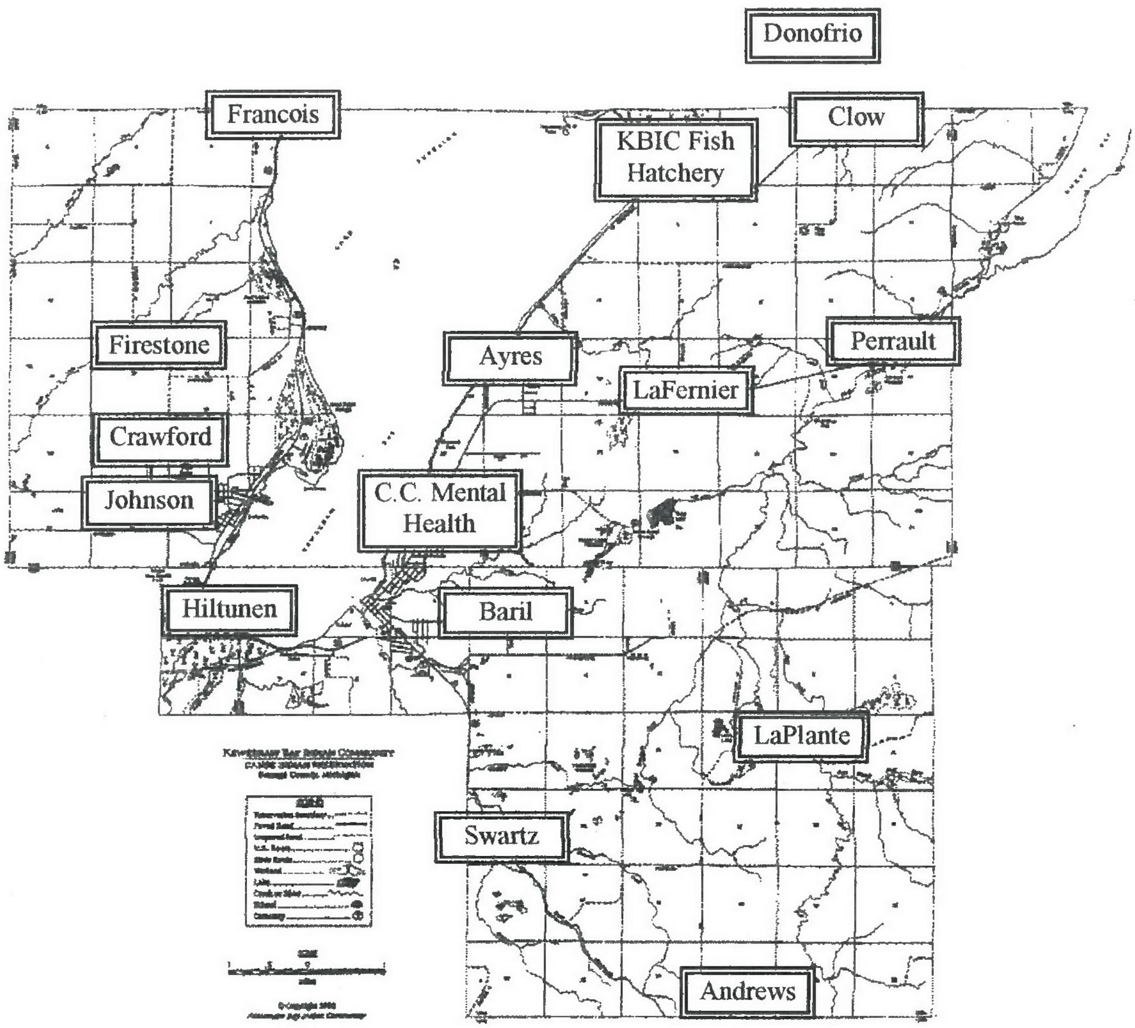


Figure 2. Approximate locations of rain gages monitored by volunteers for spring, summer and fall of 1999. Observations are compiled in Appendix A.

Table 1: Summary of precipitation monitoring by local residents of the KBIC for 1999.

Location	Date Monitoring Started	Date Monitoring Ended	Total Precipitation (Inches)	Total Number Of Days Monitored	Number Of Precipitation Days	Average Daily Precipitation (Inches/Day)	Maximum Precipitation (Inches)	Date Of Maximum Precipitation
Andrew	06/17/99	10/31/99	18.67	137	50	0.14	3.25	07/29/99
Ayres	06/01/99	10/31/99	11.50	153	47	0.08	1.31	06/21/99
Baril	06/05/99	10/31/99	17.42	149	51	0.12	1.97	08/12/99
CCMH	06/14/99	10/31/99	8.34	140	18	0.06	1.94	10/14/99
Clow	05/25/99	10/31/99	16.59	160	56	0.10	1.78	08/12/99
Crawford	06/01/99	10/31/99	17.86	153	63	0.12	1.82	08/13/99
Donofrio	06/15/99	10/31/99	14.35	139	47	0.10	1.92	07/05/99
Firestone	05/21/99	10/31/99	20.12	164	73	0.12	1.70	08/13/99
Francois	06/01/99	10/31/99	15.19	153	46	0.10	1.92	07/06/99
Hatchery	05/01/99	02/29/00	21.82	273	116	0.08	1.40	11/24/99
Hiltunen	05/26/99	10/31/99	8.75	128	24	0.07	1.01	05/31/99
Johnson	06/01/99	10/31/99	16.14	153	55	0.11	1.84	08/12/99
LaFernier	06/15/99	10/31/99	17.31	139	48	0.12	1.12	07/05/99
LaPlante	06/07/99	10/31/99	16.90	147	66	0.11	2.25	06/14/99
Perrault	06/01/99	10/31/99	17.88	153	43	0.12	1.24	06/01/99
Swartz	07/01/99	10/31/99	14.96	123	23	0.12	2.60	09/14/99
Average:			**15.86**	**154**	**52**	**0.10**	**1.82**	
Standard Deviation:			3.70	34	23	0.02	0.57	

On a daily basis the observations varied considerably and appeared to be inconsistent (see Figures A-1 through A-16). However, on overall average basis, the precipitation during the non-snow season (May through October) was consistently about 0.10 inches per day in the higher elevations and 60-80% of this at the Lake Superior elevations (Figure 3). Since the major proportion of the watershed areas reside at the higher elevations, the average precipitation rate of 0.10 inches/day is appropriate for water budget calculations.

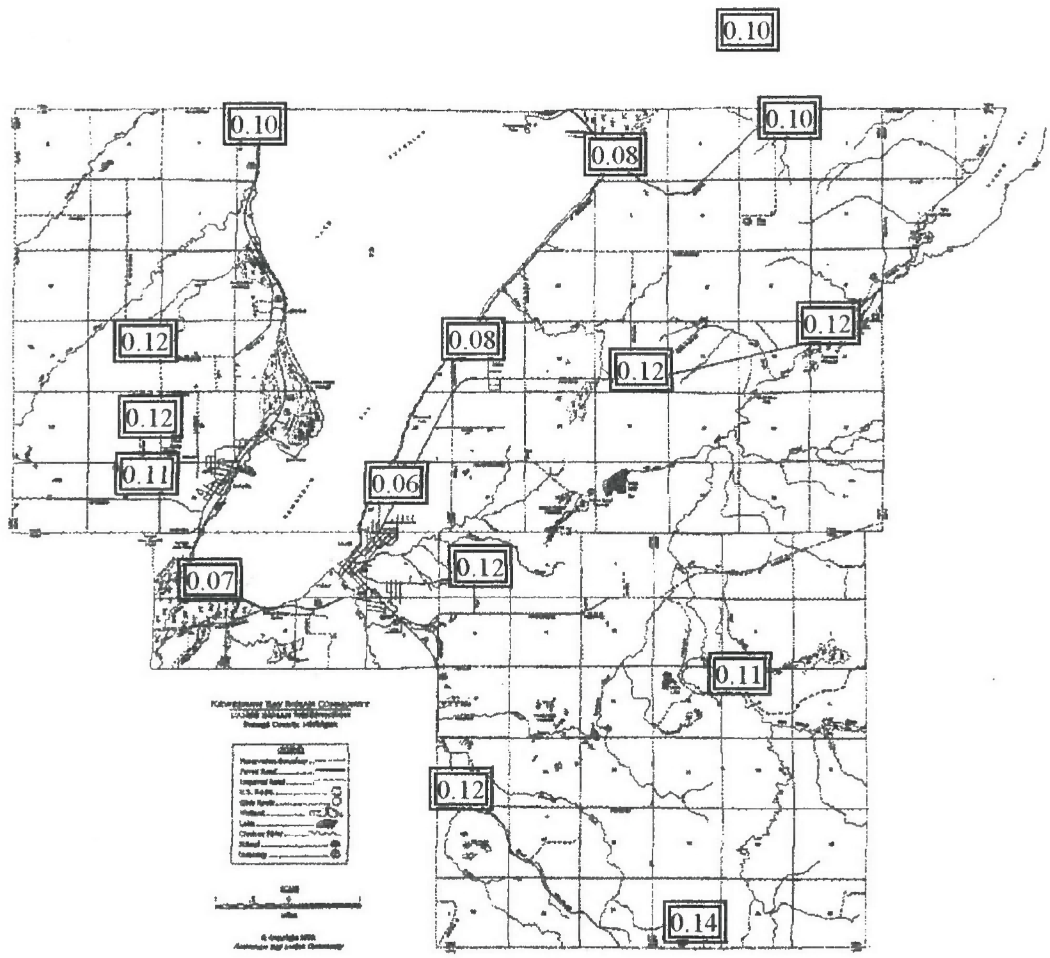


Figure 3. Average daily precipitation (inches/day) monitored by local residents with rain gages between 1 May 1999 and 31 October 1999. The KBIC Hatchery rain gage was monitored from 1 May 1999 through 28 February 2000.

The KBIC Fish Hatchery site had the most complete data set and that site continued collection of precipitation data into the winter. The observations are depicted in Figure 4 (snow data was collected in "water equivalents").

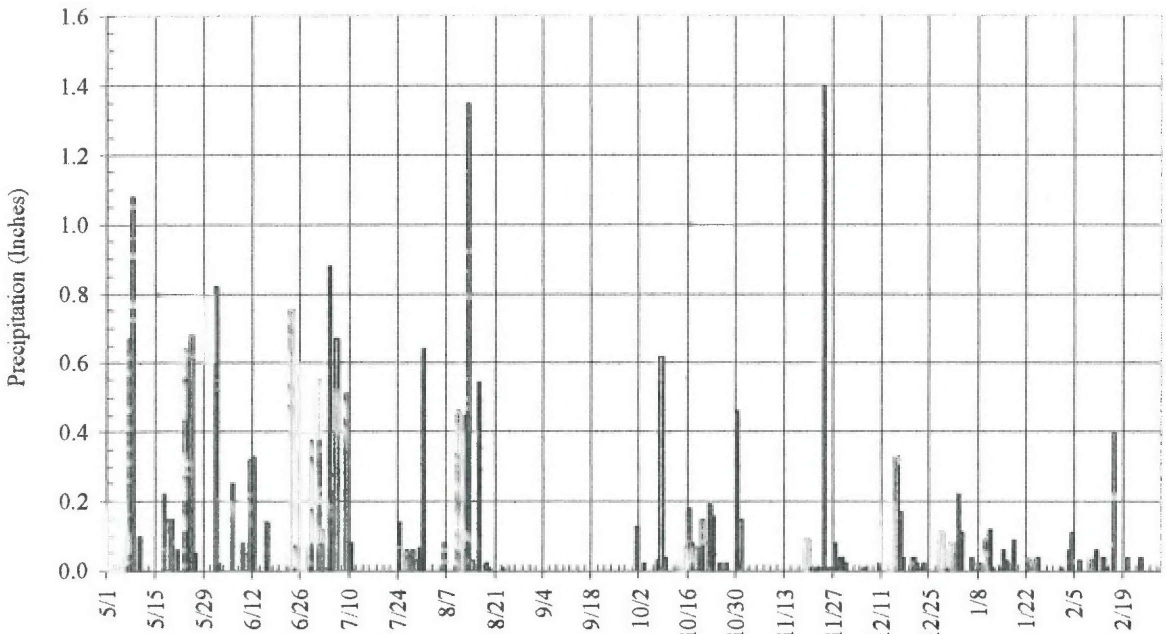


Figure 4. Daily precipitation at the KBIC Fish Hatchery.

Stream Flows

Flow measurements were recorded on a monthly basis in Daults, Denomie, and Zeba Creeks (locations of the measurements are depicted in Figure 1). The flow measurements were made by KBIC staff with a Flow-Mate 2000 (Marsh-McBirney, Inc., Frederick, MD) once a month and at least 2 days after a precipitation event. Daily flow measurements were impractical and so the approach focused on obtaining as close to base-flow conditions as possible. The consistency of the data (Figure 5) suggests that the measurements were precise, however, no independent measures of accuracy are available. Stream chemistry was also evaluated during the flow-measurement activities (see below).

Stream Chemistry

Basic water quality parameters were measured at the same times and locations of flow measurements. The results are tabulated in Table 2. Previously, the Falls River and Zeba Creek were sampled and various water quality parameters were measured by Sweat and Rheaume (1998). The parameters common to this study are listed in Table 2 for comparison purposes. The data are consistent for all applicable parameters except chloride and nitrate+nitrite, which were so low that the discrepancies are probably due to the differences in analytical procedures.

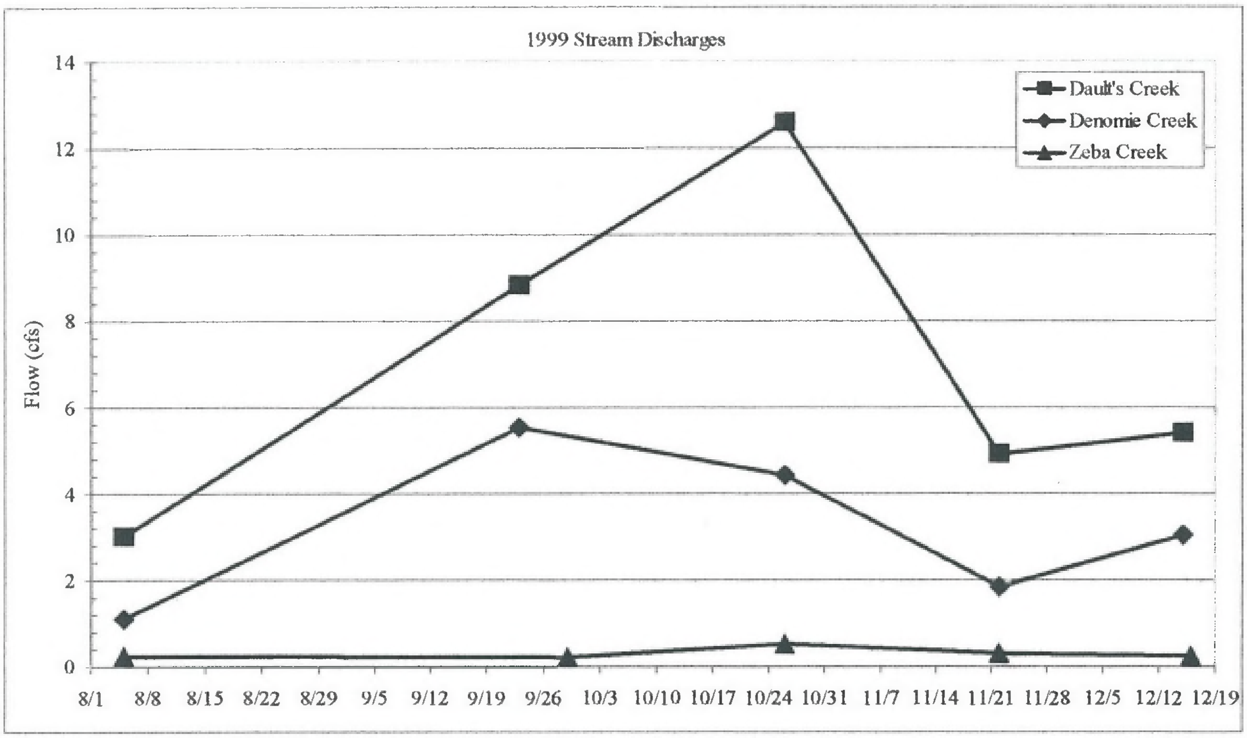


Figure 5. Stream discharges measured in late summer through fall of 1999.

Data Analysis

Water Budget Estimates

A general water budget for a watershed under steady-state conditions follows:

$$\textit{Precipitation} + \textit{Inflows} + \textit{Inputs} = \textit{Evapotranspiration} + \textit{Outflows} + \textit{Withdrawals} \tag{1}$$

Precipitation is the total sum of all atmospheric deposition of rain and snow (in water equivalent). *Inflows* are categorized here as natural sources of water such as groundwater seepage and surface runoff into the watershed. *Inputs* are potential anthropogenic sources such as irrigation, infiltration, and well injections. *Evapotranspiration* is the sum of evaporation and transpiration. *Outflows* are the natural water discharge from streams and groundwater out of the watershed. *Withdrawals* are the result of water extraction from waterwell pumping.

The watersheds in this study area have common characteristics with respect to these hydrological components as listed Table 3. The general water budget can be simplified for these areas to:

$$\textit{Precipitation} = \textit{Evapotranspiration} + \textit{Outflows} \tag{2}$$

Table 2: Stream chemistry measured in the field. Previous data (Sweat and Rheaume, 1998) published (shown in *italics*) for Falls River and Zeba Creek are listed for comparison.

Stream	Date	Time	Conductivity (µS)	pH	Cl (mg/L)	Temperature (C)	Ammonia (mg-N/L)	Acidity (mg-CO_2/L)	DO (mg/L)	Alkalinity (mg-$CaCO_3$/L)	Total Hardness (mg-$CaCO_3$/L)	Nitrate-Nitrite (mg-N/L)
Daults	8/5/99	---	103.1	7.5	0.6	13.4	1.2	35	10	68	86	0
Daults	9/23/99	---	69	7.5	0.6	11.5	0	25	10	51	68	0
Daults	10/26/99	9:30 AM	53.7	8.5	---	4.1	0	---	13	25	43	0
Denomie	8/5/99	---	114.5	7.5	0.6	13.4	2.4	35	9	120	120	0
Denomie	9/23/99	---	155.5	8	0.6	12	0	35	10	103	120	0
Denomie	10/26/99	10:10 AM	133.5	8	---	5.2	0	---	13	78	90	0.01
Falls	*10/30/91*	*12:20 PM*	*145*	*7.8*	*4.4*	*5.0*	*0.01*		*12.8*	*64*	*68*	*<0.05*
Zeba	8/5/99	---	164.7	7	0.6	15.6	1.2	60	10	120	120	0
Zeba	9/29/99	---	177.7	7.5	0.6	8.9	0	25	11	120	120	0
Zeba	10/26/99	11:00 AM	171.8	8.1	---	5.8	0	---	11	96	104	0
Zeba	*10/30/91*	*8:20 AM*	*219*	*7.8*	*4.5*	*3.0*	*0.03*	---	*12.0*	*100*	*110*	*0.50*

Table 3: Water budget components and their significance for the study area.

Water Budget Category	Probable Source/Cause	Estimation Approach	Relative Importance for this Study Area	Comments
Precipitation	Rain and snowmelt	Measured with rain and snow gauges	Primary water input	
Inflows	Overland flow	Assumption	Negligible	Water budget boundary coincides with watershed boundary
	Groundwater inflow	Assumption	Negligible	Water budget boundary coincides with watershed boundary
Inputs	Residential septic fields	Assumption	Balances with waterwell withdrawals	No water from outside the watershed is pumped into the watershed.
Evapo-transpiration	Evaporation and forest transpiration	Thornthwaite method	Nearly equal to precipitation	Watershed is nearly entirely forested
Outflows	Stream discharge	Measurement	Significant but small percentage of total water budget	
	Groundwater discharge	Assumption	Negligible	Area available for discharge is very small, majority of outflow is from stream discharge
Withdrawals	Pumping of residential wells	Assumption	Total extraction is small and is mostly returned to the system via infiltration	Only residential wells exist in the watersheds and since each residence has its own septic/drainfield, the extracted water is returned with very little opportunity for consumptive losses.

Steady-state conditions exist when the system reaches a balance overall between the sum of all inflows and outflows and when waterlevels within the watershed stabilize. Without intensive monitoring, beyond the scope of this study, there is no practical way to justify the assumption of steady-state conditions. Although significant daily, seasonal, and annual variations exist, constructing a water budget over a year-long basis will be representative of annual average conditions as long as no major changes occur in the watershed such as large-scale alterations of land use or water development (e.g., community wells, new dams, etc.). For the areas studied in this project, no substantial changes occurred and so a steady-state flow condition was a reasonable assumption.

For watersheds where precipitation, evapotranspiration, and stream runoff are the predominant components, the stream runoff will be equivalent to the *net infiltration* (precipitation – evapotranspiration) in the watershed. Precipitation can be monitored directly. Evapotranspiration (ET) can not be measured directly and is usually either an estimated property based on other directly measured conditions (e.g., temperature) or inferred by solving the water budget equation for ET. Consider, first, the Zeba Creek watershed where the average annual precipitation was approximately 36 inches (3.0 ft) of water. The average baseflow, based on the four months of monitoring, was 0.25 cfs. The watershed encompasses an area of 3.3 square miles (93,000 ft^2). Therefore, the water budget for Zeba Creek in terms of <u>measured</u> quantities is:

$$3.0 \text{ ft/yr} \times 93{,}000{,}000 \text{ ft}^2 = \text{ET} \times 93{,}000{,}000 \text{ ft}^2 + 0.25 \text{ ft}^3/\text{s} \times 31{,}536{,}000 \text{ s/yr}$$

which yields an estimate of the annual ET for the Zeba Creek watershed of 2.9 ft. Therefore, the infiltration within the watershed is less than 5% of the annual precipitation. This difference is within the error of the measurements in precipitation and stream flow, and thus the stream flow component of the water budget is statistically insignificant for the Zeba Creek watershed.

Evapotranspiration rates are also often estimated based on climatological data (daily temperature, wind speeds, solar radiation, etc.) and soil and vegetation conditions. Only precipitation and temperature data exist for the watersheds in this study, so the Thornthwaite method is probably the most suitable approach for independently estimating ET. The details for calculating ET by the Thornthwaite method are given by Sellinger (1996) and the results using Sellinger's computer program (cf. ftp://ftp.glerl.noaa.gov/publications/tech_reports/glerl-101) are listed in Table 4 for the conditions observed at the KBIC Fish Hatchery.

The Thornthwaite method uses measurements for monthly mean precipitation and temperature, along with a general characterization of soil and vegetation conditions, to estimate actual ET. Other methods require measurements of other parameters such as wind speed, solar radiation, and dew point. A more sophisticated approach would not necessarily yield an estimate with a higher degree of accuracy, nor is a higher degree of accuracy warranted.

Table 4. Evapotranspiration (ET) estimates for the Keweenaw Bay region. Estimates of Actual ET were calculated using the Thornthwaite method using measured mean monthly temperature (daily temperatures are shown in Appendix B: Figure B-1) and precipitation (from Figure 4) at the KBIC Fish Hatchery.

Month	Year	Mean Temperature (Celcius)	Precipitation (mm)	Precipitation (inches/day)	Actual ET (mm)	Actual ET (inches/day)
May	1999	12	111	0.146	78	0.102
June	1999	17	90	0.118	113	0.148
July	1999	20	103	0.135	132	0.173
August	1999	18	75	0.098	105	0.138
September	1999	12	66	0.087	66	0.087
October	1999	7	58	0.076	31	0.041
November	1999	5	43	0.056	19	0.025
December	1999	-3	25	0.032	0	0.000
January	2000	-5	24	0.031	0	0.000
February	2000	-2	22	0.029	0	0.000
Total			**546**		**544**	
Average		*8*		*0.059*		*0.059*

Figure 6 graphically depicts the measured monthly precipitation and estimated actual evapotranspiration from May 1999 through February 2000. Seasonally, when precipitation exceeds ET, then the excess precipitation is, in varying proportions, infiltrating the soils and running off into streams. During the summer when ET exceeds precipitation, then groundwater is supplying the stream flow and also being drawn towards the ground surface by capillary action to replenish soil moisture lost to ET.

Overall, the Thornthwaite method suggests a balance between precipitation and evapotranspiration for this study area, which is common for heavily forested watersheds lacking in development that significantly alters infiltration. The same results also apply to the Denomie and Daults Creek watersheds.

A balance between precipitation and evapotranspiration is important from the perspective of land development. Development that negatively affects infiltration and/or enhances evaporation (transpiration is probably already at a maximum for the areas in this study), will result in decreased water supplies and reductions in stream flows. There are no practical alterations that could increase transpiration, as the transpiration rate is probably already near the maximum for these areas considering the dense vegetation. Changes that would cause an increase in the evaporative component would cause a concomitant decrease in transpiration. Hence the ET rate is, for all intensive purposes, fixed according to the average near-surface soil conditions.

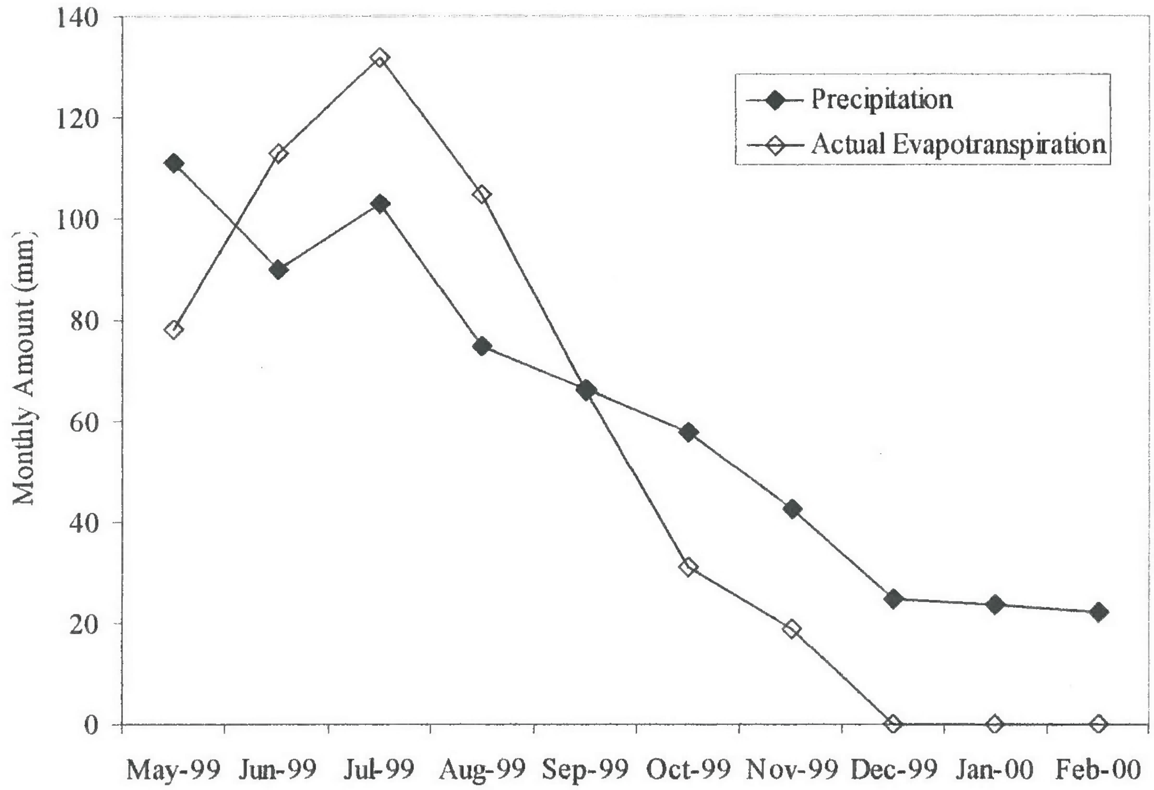


Figure 6. Comparison of average monthly precipitation to an estimate of actual evapotranspiration based on the Thornthwaite method using mean monthly precipitation and temperatures observed at the KBIC Fish Hatchery.

Geological Conditions

Well log records, from the locations listed and summarized in Table 5, were reviewed for the areas included in this study.

The Zeba creek watershed is primarily underlain by Jacobsville sandstone, according to Doonan and Byerlay (1973) and confirmed by the well logs. The surficial deposits (overburden) are primarily are ground and water-laid moraine deposits, made up of loose till, containing beds of lacustrine sand and poorly sorted gravel (Doonan and Byerlay, 1973), and vary in thickness from a few feet to 80 feet and more. The well logs in the Zeba creek watershed could be characterized into two categories based on overburden thickness: (1) "thin" overburden is less than 30 feet deep and (2) "thick" overburden is more than 30 feet deep.

Table 5: Summary of available well logs and general geological conditions.

Township Number (N)	Range Number (W)	Section Number	Watershed(s)	Number of Wells in Section	Generalized Geological Description
50	32	31	Denomie	1	thin overburden above bedrock (not identified)
50	33	15	Denomie	4	thin overburden above bedrock (some not identified, slate, and granite)
50	33	22	Denomie & Daults	9	thin overburden above bedrock (some not identified, slate), one well in thick overburden never reaching bedrock
50	33	26	Denomie	1	thick overburden above slate
50	33	27	Denomie	1	thick overburden above slate
50	33	35	Denomie	1	thick overburden above slate
50	33	36	Denomie	2	thick overburden above bedrock (not identified)
51	32	16	Zeba	1	thin overburden above sandstone
51	32	18	Zeba	6	thin-thick overburden above sandstone
51	32	20	Zeba	5	thin overburden above sandstone with underlying shale
51	32	21	Zeba	13	thin overburden above sandstone

The term "thin" overburden refers herein to a thickness of less than 30 ft; "thick" overburden refers to deposits more than 30-ft thick. Bedrock thicknesses were typically not determined as the boreholes did not penetrate the entire unit.

Most of the Falls River watershed, which includes both Denomie and Daults watersheds, is underlain by metamorphic rocks, primarily slate, according to Doonan and Byerlay (1973) and most of the well logs. Many of the well logs referred to the rocks only as "bedrock," but it is reasonable to assume that the drillers were referring to slate. The most southeastern edge of the watersheds overlies granite and/or gneiss (Doonan and Byerlay, 1973), but data for this region is lacking and only one well log indicates that granite was present. In the region around where Denomie and Daults creeks discharge into the Falls River (northwestern-most third), the surficial deposits are of the same origin as in the Zeba Creek watershed. This comprises about one-third of their watershed areas. The surficial deposits in the middle third of both watersheds is characterized by higher elevation moraine deposits that are primarily more compacted till. The uppermost third of the watersheds (southeastern-most third) are very thin and bedrock outcrops at the surface are common, but some localized deposits of recent alluvium (Doonan and Byerlay, 1973) surround the community of Herman and comprise the headwater of Daults Creek. Well logs for the Herman area were not evaluated as they are outside the reservation.

Hydrogeological Conditions

Potentiometric maps of the study areas have been prepared and published by Doonan and Byerlay (1973) and Sweat and Rheaume (1998). These maps are consistent with the general assumption that regional groundwater flow follows the surface topography (cf. Freeze and Cherry (1979)). Large pumping wells, irrigation and infiltration systems, and hydraulic structures such as dams can cause subsurface flows to deviate significantly from the topographic trends, but none of these conditions exist in this study area. Therefore the general flow direction is trending toward the northwest for both the Falls River and Zeba Creek watersheds. The water table tends to vary between 6 to 70 feet below ground surface across the study area, but for most wells the water table is between 10 and 30 feet deep.

All of the wells in the study area were residential and installed using either cable-tool or rotary drilling methods by local drilling contractors. Well diameters were usually between 4 and 8 inches and installed to depths of 100-300 feet. Steel casing extended from a foot or so above the ground surface to a few feet into the bedrock, so the pumped water was being drawn through the bedrock into an open borehole. In general, well productivity would be greatest for aquifers in unconsolidated deposits, but most of the glacial drift lies either above the water table or the saturated thickness in these deposits is too shallow for acceptable yields. Well capacities for bedrock aquifers are typically highest in sandstone, lower in slate, and then lowest in granite and gneiss.

Drillers test the well capacity by monitoring the pumping water level and pumping rate for periods ranging from a few hours to two days or until the pumping level falls below pump intake, which occurs when well yields are low. Well performance varied from less than 1 gallon per minute (gpm) to as much as 30 gpm of sustainable flow. About half of the wells in the sandstone aquifers yielded sustainable flows of 5 gpm or more; only 20% of the wells in the slate bedrock aquifers produced at a sustainable rate.

With a few exceptions, the productivities of wells in the Zeba creek watershed varied inversely with overburden thickness. In general, the wells with an overburden less than 30-ft thick yielded sustainable flows (~5 gpm) and the wells where the glacial drift deposits were thicker than 30 feet would usually be pumped "dry," which is the temporary condition where the water level in the pumping well falls below the pump intake and the pumping is stopped until the well recovers. One explanation for the curious inverse trend between overburden thickness and well capacity is that the sandstone underlying the regions of thin overburden is more fractured, which is where the highest proportion of flow is occurring (Sweat and Rheaume, 1998). The more weathered and fractured sandstone was probably eroded during glacial retreat, producing areas where the glacial drift is thick. Therefore the wells where the glacial drift is thick are drawing water from sandstone that is probably less fractured and tighter than the wells where the glacial drift is thin. Better yields might be obtained from some wells by installing a properly designed screen in the lower most portion of the glacial drift, if the water table is 40 feet or more above the bedrock and the glacial deposits do not exhibit significant fractions (e.g., >10% by weight) of fine materials.

The wells in the Daults and Denomie watersheds were less productive. Only 20% of the wells could produce sustainable yields of 5 gpm or more. There were no clear trends that would suggest where the probability of yielding a productive well is greatest, probably because the productivity of a given well is a function of whether it intercepted a sufficient number of water-producing fractures.

Conclusions

Precipitation monitoring during the May through October of 1999 observed a range of average daily precipitation of 0.06 inches/day at L. Superior elevations to 0.12 inches/day at the higher elevations. Daily precipitation monitoring at elevations representative of the variation within a watershed are needed.

The Thornthwaite method for estimating evapotranspiration was consistent with waterbudget estimates of evapotranspiration. Most of the precipitation is returned to the atmosphere via evapotranspiration for the three watersheds in this study.

Stream flows were measured on a monthly basis in Zeba, Daults, and Denomie creeks. Monthly stream-flow monitoring was not frequent enough to yield an accurate water budget analysis and to provide data that will be needed to observe seasonal and other short-term changes in stream flows and water quality. Stream gauging stations that can be monitored at least weekly should be considered for more comprehensive watershed studies.

Stream flows represent a small percentage of the annual transfer of water in a watershed and are influenced significantly by short-term precipitation events. Water table elevations will provide baseline data for monitoring long-term changes in the hydrology of a watershed, and a systematic approach for monitoring water table elevations should be implemented.

Water quality in terms of chemical parameters has not changed significantly since 1991 (no data exists prior to 1991) for Zeba, Denomie, and Daults Creeks. Sedimentation of creeks is a concern throughout the Upper Peninsula and stream-borne sediment transport should be included in all future monitoring programs.

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Doonan, C.J., and J.R. Byerlay (1973). Ground Water and Geology of Baraga County, Michigan, State of Michigan, Lansing, Michigan, 26 pp. and 2 maps in pocket.

Freeze, R.A., and J.A. Cherry (1979). Groundwater, Prentice-Hall, Inc., Englewood Cliffs, New Jersey, 604 pp.

Sellinger, C.E. (1996). Computer Program for Estimating Evapotranspiration Using the Thornthwaite Method, NOAA Technical Memorandum ERL GLERL-101, Great Lakes Environmental Research Laboratory, National Oceanic and Atmospheric Administration, Ann Arbor, November 1996.

Sweat, M.J., and S.J. Rheaume (1998). Water Resources of the Keweenaw Bay Indian Community, Baraga County, Michigan, U.S. Geological Survey, Denver, Colorado, 33 pp.

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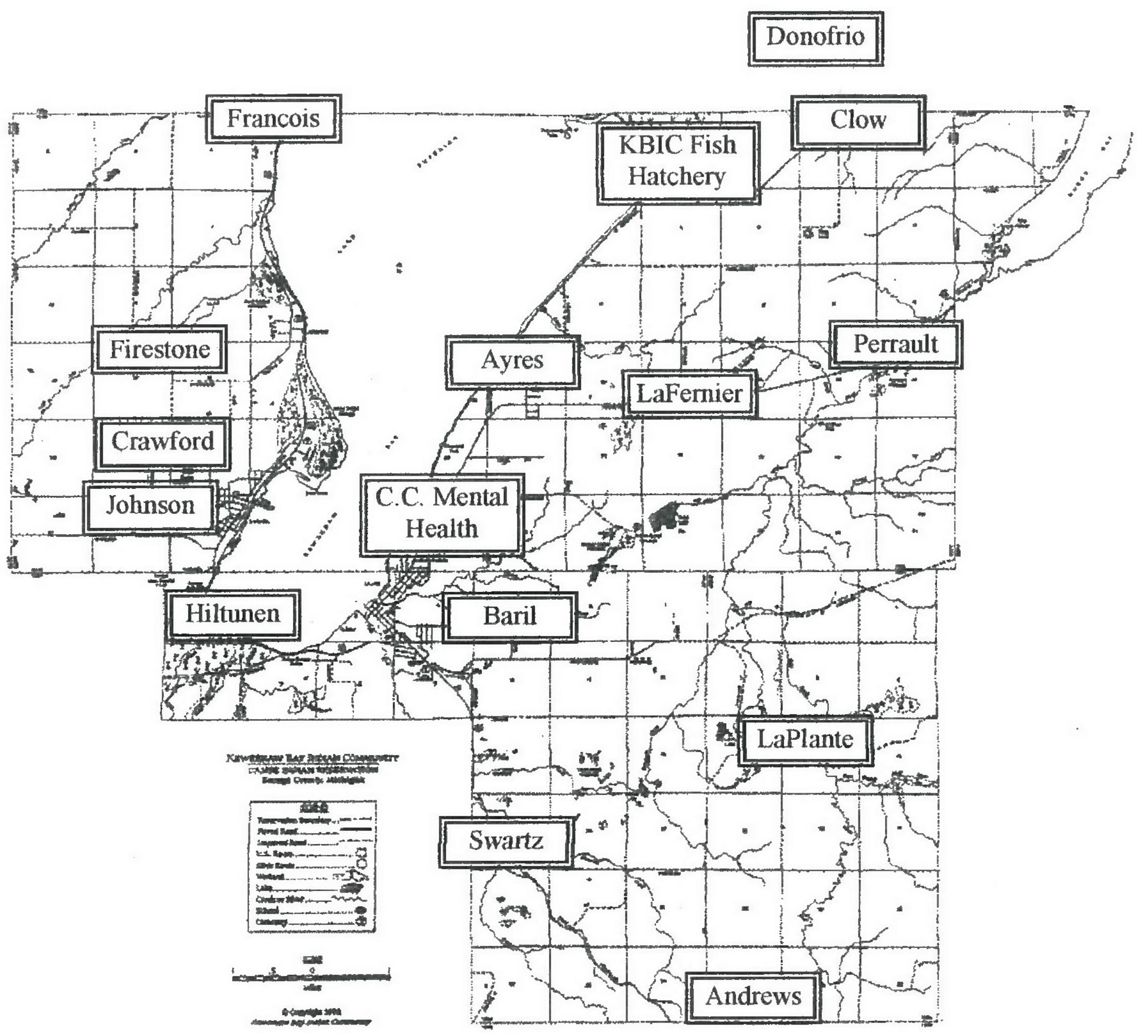
Berndt, L.W. Soil Survey of Baraga County Area Michigan, U.S. Department of Agriculture Soil Conservation Service, 306 pp. plus maps.

Farm and Home Publishers, LTD. Baraga County Michigan Plat Book, Belmond, IA, 64 pp.

Stone, W.J. (1999). Hydrogeology in Practice: A Guide to Characterizing Ground-Water Systems, Prentice Hall, Upper Saddle River, New Jersey, 248 pp.

Appendix A. Rain gage monitoring in Baraga County for 1999 by local residents and two local agencies. Locations are shown in figure below.



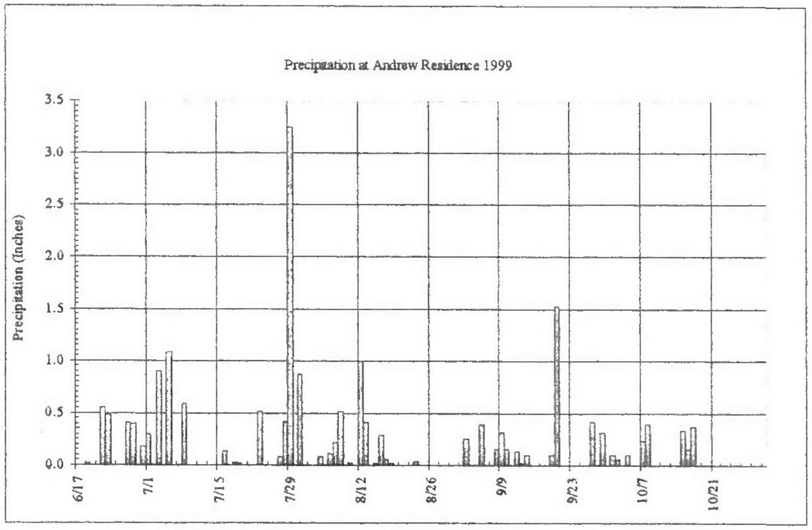


Figure A-1. Precipitation monitored at Andrews residence (Baraga County, MI) in 1999.

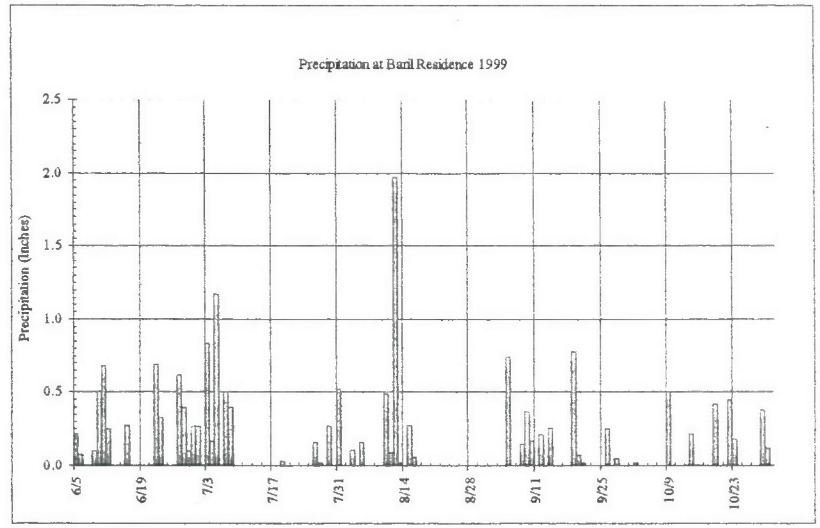


Figure A-3. Precipitation monitored at Baril residence (Baraga County, MI) in 1999.

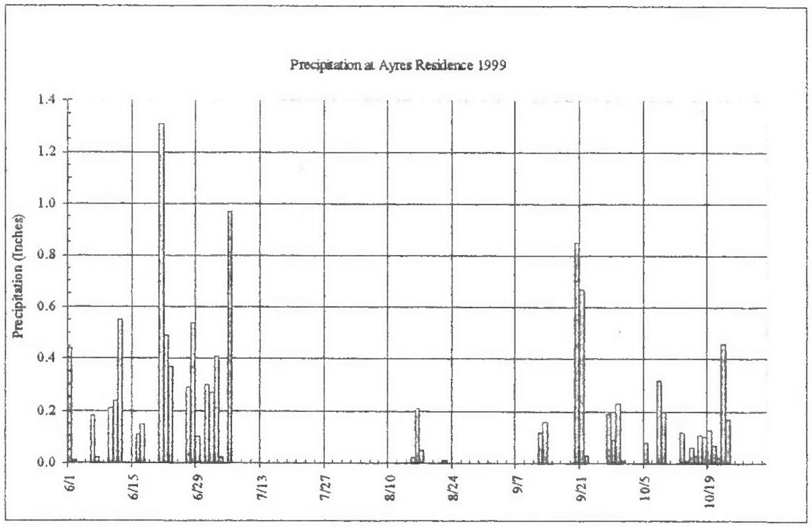


Figure A-2. Precipitation monitored at Ayres residence (Baraga County, MI) in 1999.

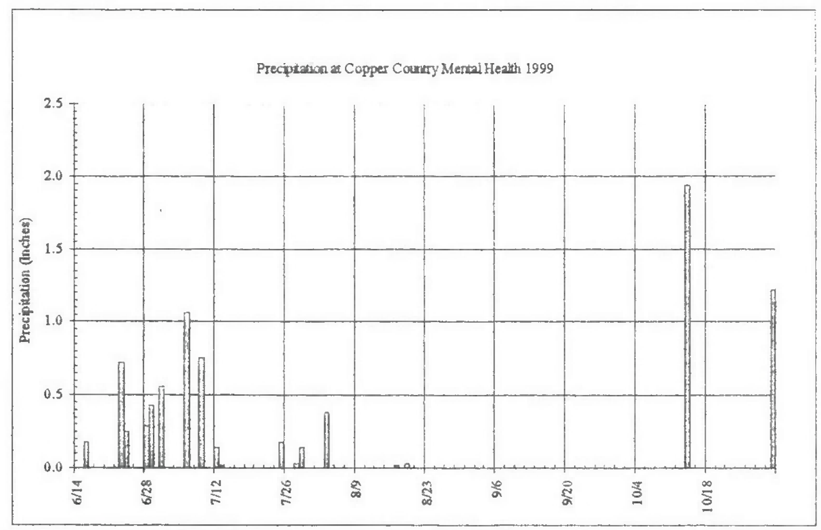


Figure A-4. Precipitation monitored at Copper Country Mental Health (Baraga, MI) in 1999.

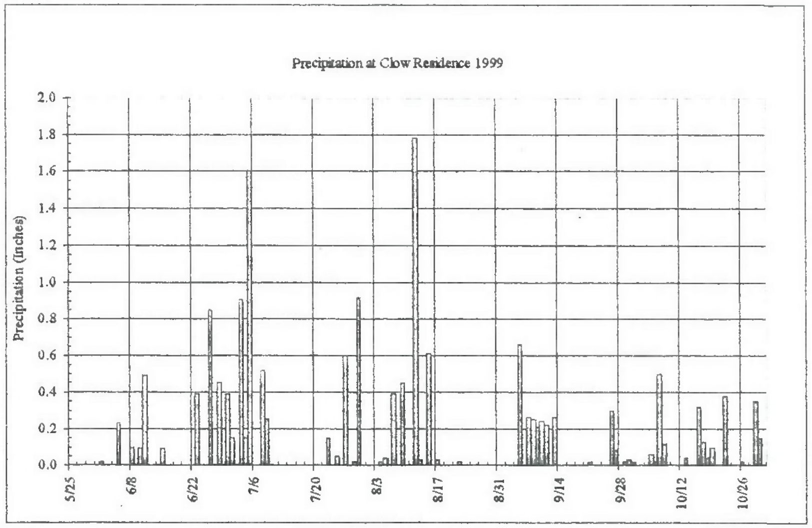


Figure A-5. Precipitation monitored at Clow residence (Baraga County, MI) in 1999.

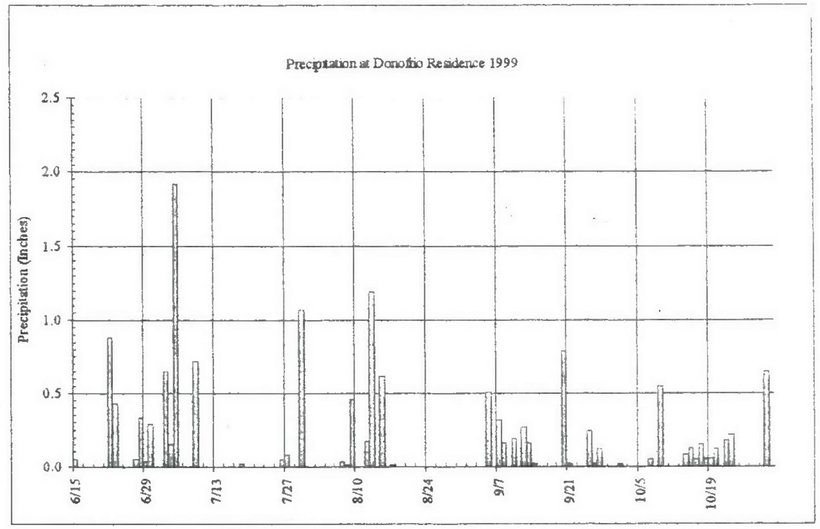


Figure A-7. Precipitation monitored at Donofrio residence (Baraga County, MI) in 1999.

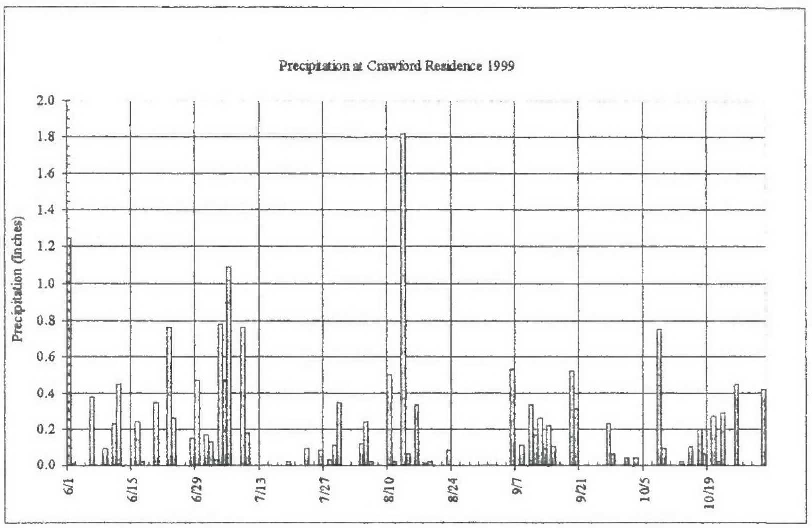


Figure A-6. Precipitation monitored at Crawford residence (Baraga, MI) in 1999.

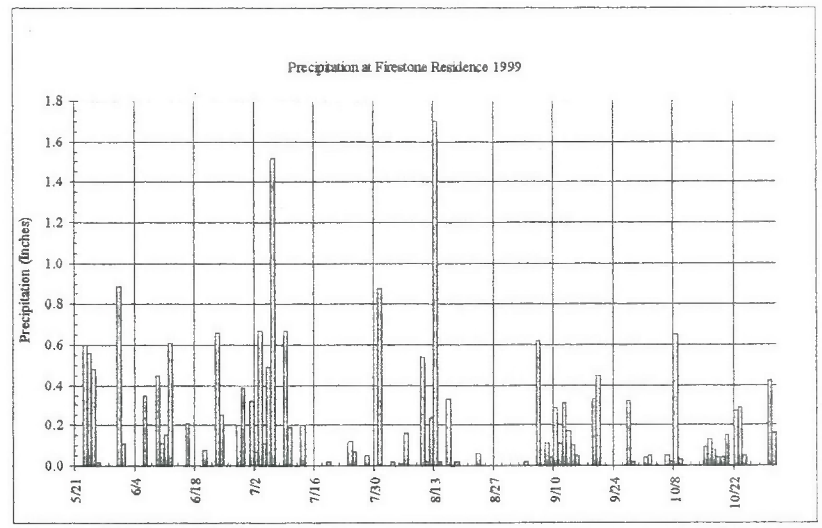


Figure A-8. Precipitation monitored at Firestone residence (Baraga, MI) in 1999.

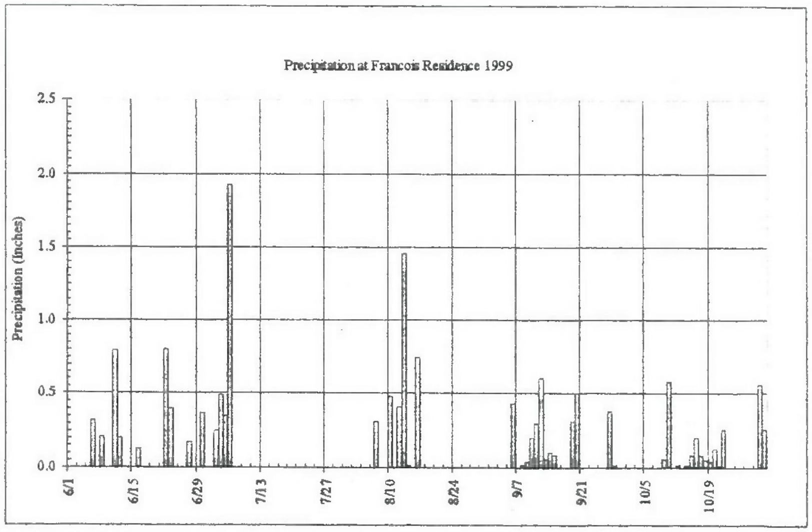


Figure A-9. Precipitation monitored at Francois residence (Baraga County, MI) in 1999.

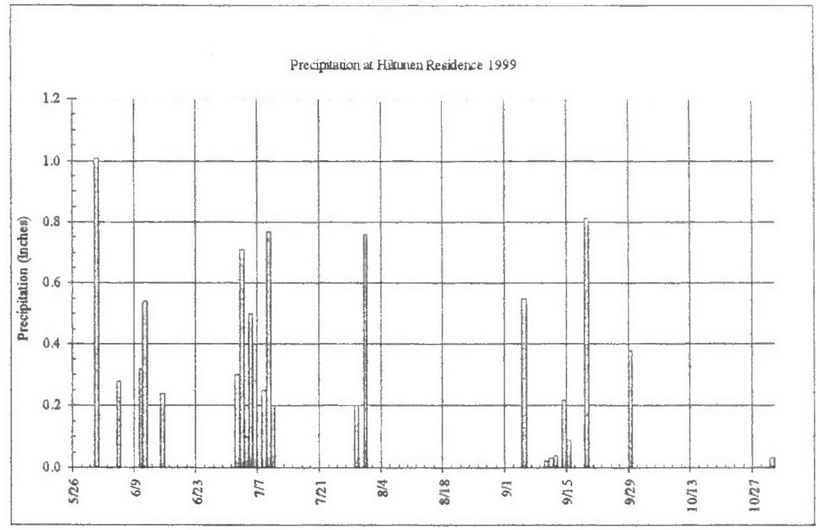


Figure A-11. Precipitation monitored at Hiltunen residence (Baraga County, MI) in 1999.

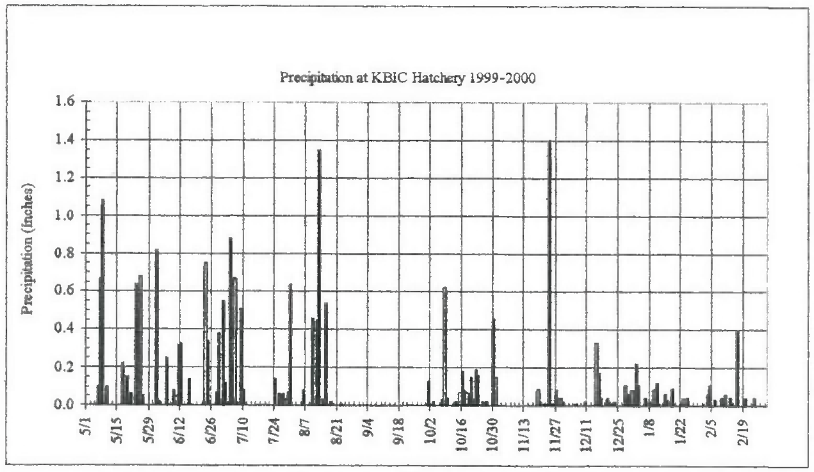


Figure A-10. Precipitation monitored at KBIC Tribal Fish Hatchery (Baraga County, MI) in 1999.

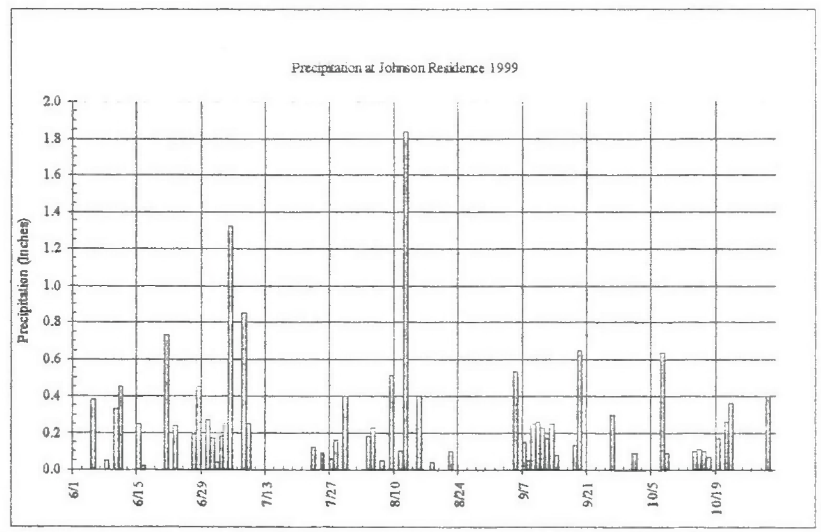


Figure A-12. Precipitation monitored at Johnson residence (Baraga, MI) in 1999.

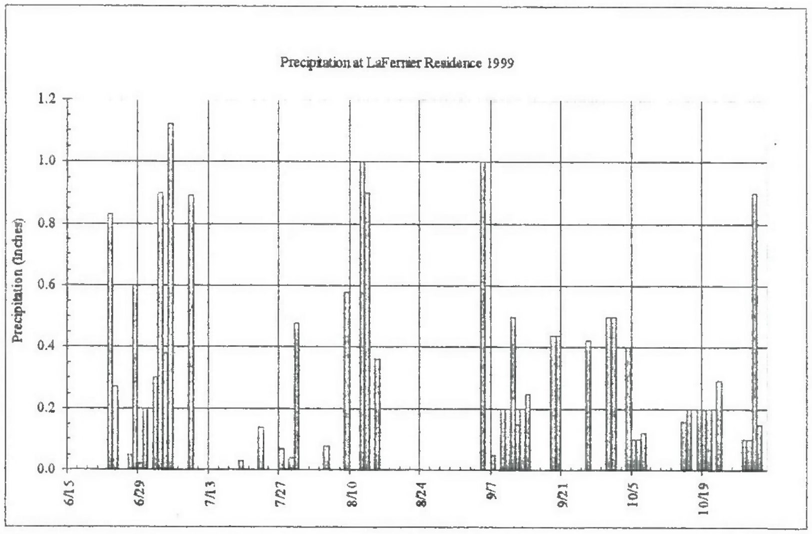


Figure A-13. Precipitation monitored at LaFernier residence (Baraga County, MI) in 1999.

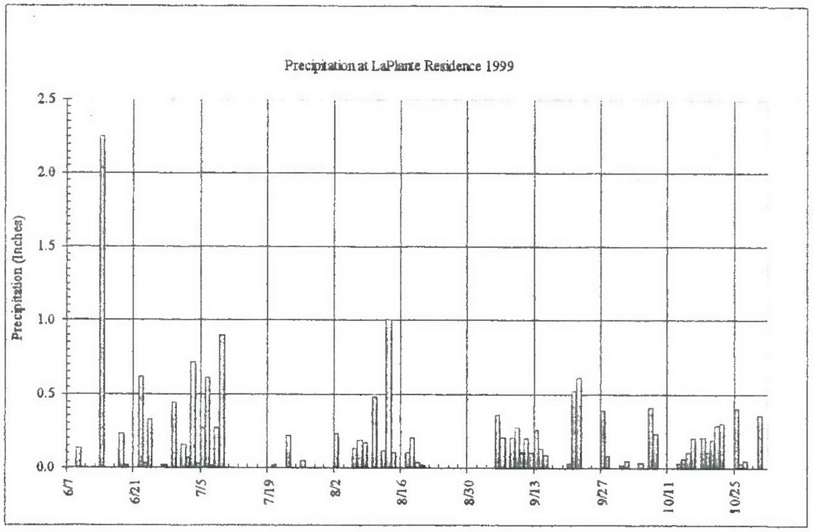


Figure A-14. Precipitation monitored at LaPlante residence (Baraga County, MI) in 1999.

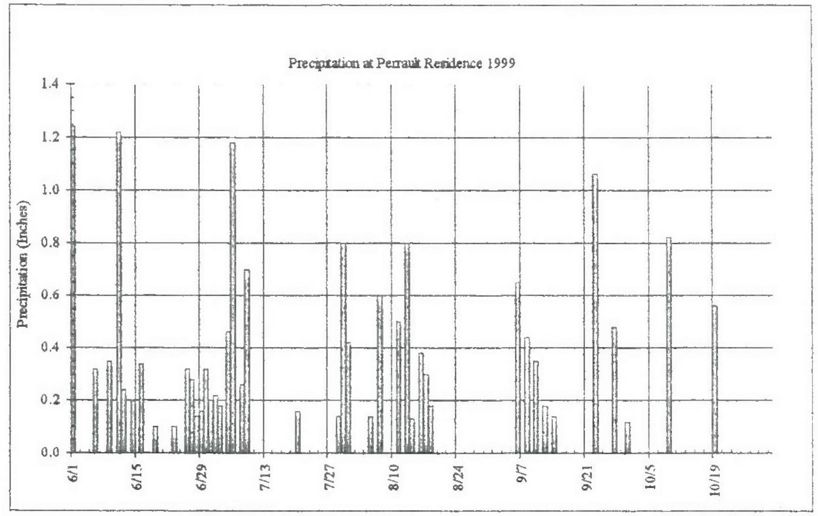


Figure A-15. Precipitation monitored at Perrault residence (Baraga County, MI) in 1999.

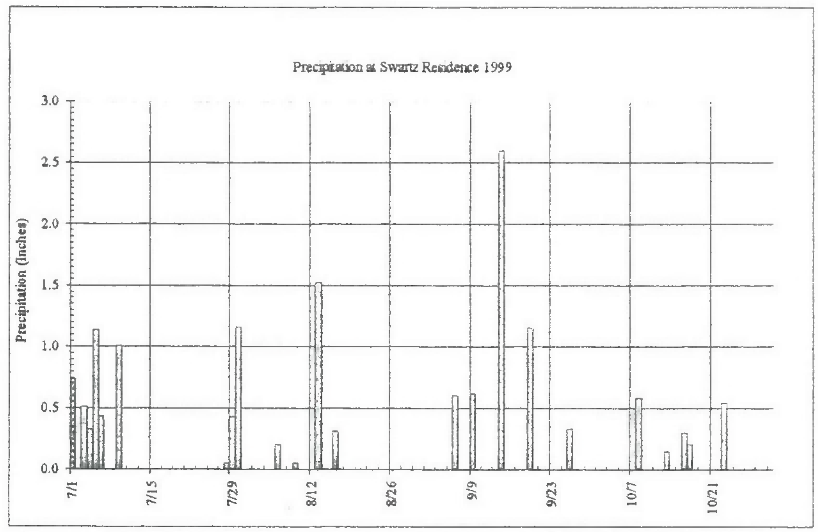


Figure A-16. Precipitation monitored at Swartz residence (Baraga County, MI) in 1999.

Appendix B. Daily temperatures at KBIC Fish Hatchery (Baraga County, MI)

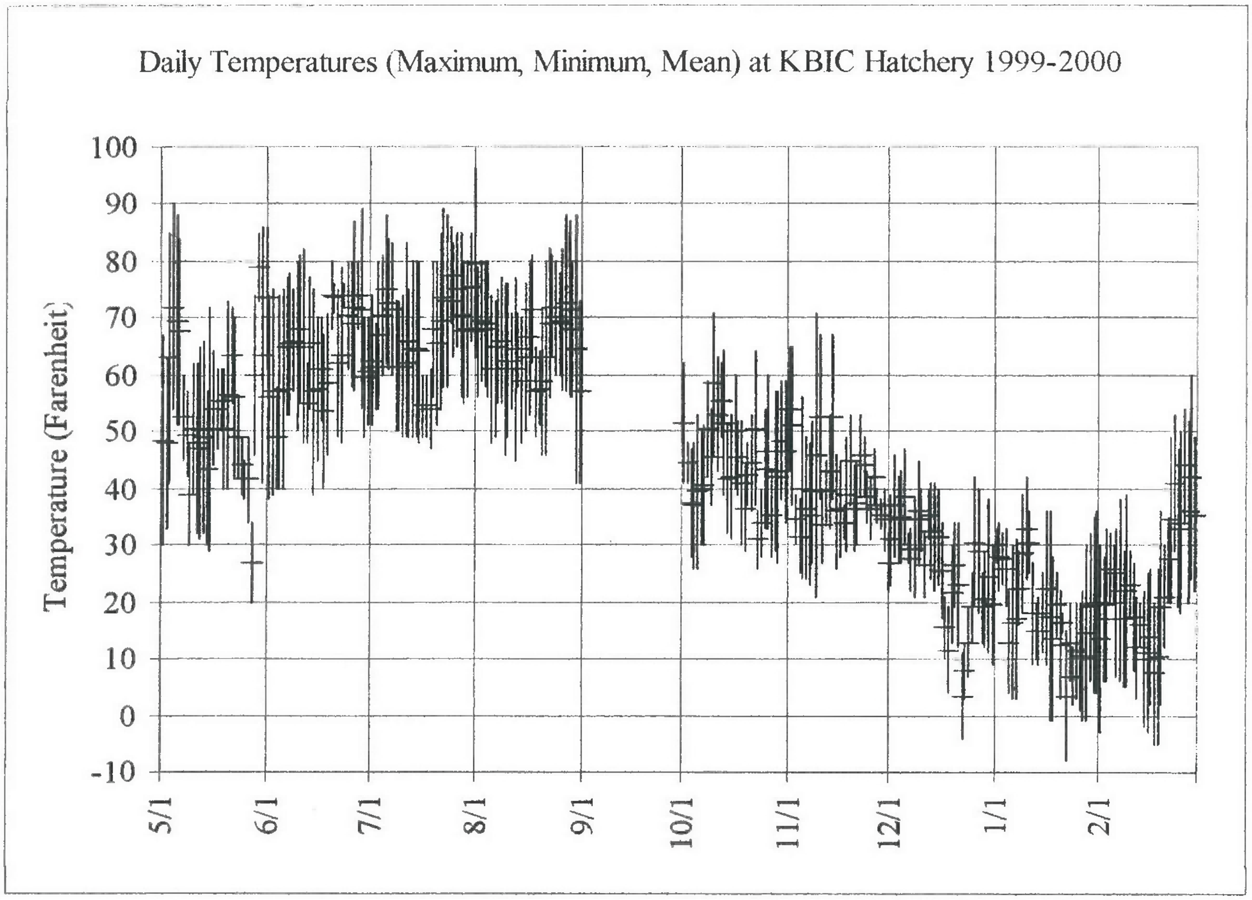


Figure B-1. Daily temperatures (maximum, minimum, and median) observed at the KBIC Fish Hatchery, May 1999 through February 2000.

Modeling of the Hydrology of the Zeba (Little Silver) Creek Watershed: Conceptual Picture, Model Configuration, and Status

John S. Gierke, Ph.D., P.E. (jsgierke@mtu.edu; Voice: 906.485.2535; Fax: 906.487.3371)
Associate Professor of Geological and Environmental Engineering
Department of Geological Engineering & Sciences
Michigan Technological University
1400 Townsend Drive
Houghton, MI 49931-1295

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Introduction

A regional groundwater flow model is being developed to simulate the subsurface flow of water in the Zeba (Little Silver) Creek watershed, which is located within the L'Anse Indian Reservation. An outline of the watershed is depicted in Figure 1. The watershed boundaries were determined by delineating the topographic divide starting where Zeba Creek discharges into Lake Superior.

Watershed Characterization

During the fall field characterization season of 2000 (September – November) and the ensuing spring season of 2001 (April-May), the watershed assessment student project group worked on planning and conducting field surveys and tests of:

1) depths to bedrock, glacial drift thickness

2) water table elevations in wells

3) bedrock transmissivity

Our winter (December 2000 – March 2001) activities included evaluating the data we collected in the fall and in planning the spring activities. Since this was the first time for any of the students to plan field work, the time it took for planning an activity was much longer than was estimated based on our best guesses at the time the Workplan was submitted.

The students submitted a report on our characterization work in November 2000 and then a "final" report in May 2001. The quality of their final report was not as high as I would like to submit, so I am currently rewriting most of it.

Conceptual Picture and Model Grid

During the winter the students were introduced to modeling with MODFLOW and performed a couple of simple, recipe-like exercises to become familiar with running MODFLOW. A pre- and post-processor interface for MODFLOW, called GMS, was being used to build a conceptual model of the watershed, translate the conceptual model into a MODFLOW model grid and input. A subgroup was formed to concentrate on developing a model for the Zeba Creek watershed, but software problems with GMS delayed progress on this activity until the end of spring semester, which is when I had t--for all intensive purposes--restart the modeling (see above).

The region is being modeled as two geological layers, a surficial layer of unconsolidated glacial drift overlying a thick sequence of sandstone. The topography of the glacial deposits were obtained with digital elevation model (DEM) data, which are displayed as contours in Figure 1. The thin, dark brown lines are USGS topographic contours in units of meters above mean sea level (amsl), the bolder lines are intervals of 50 meters. The yellow contours are the DEM derived contour lines that should correspond to the 50-m USGS topographic contours, labeled in feet amsl. The correspondence is excellent.

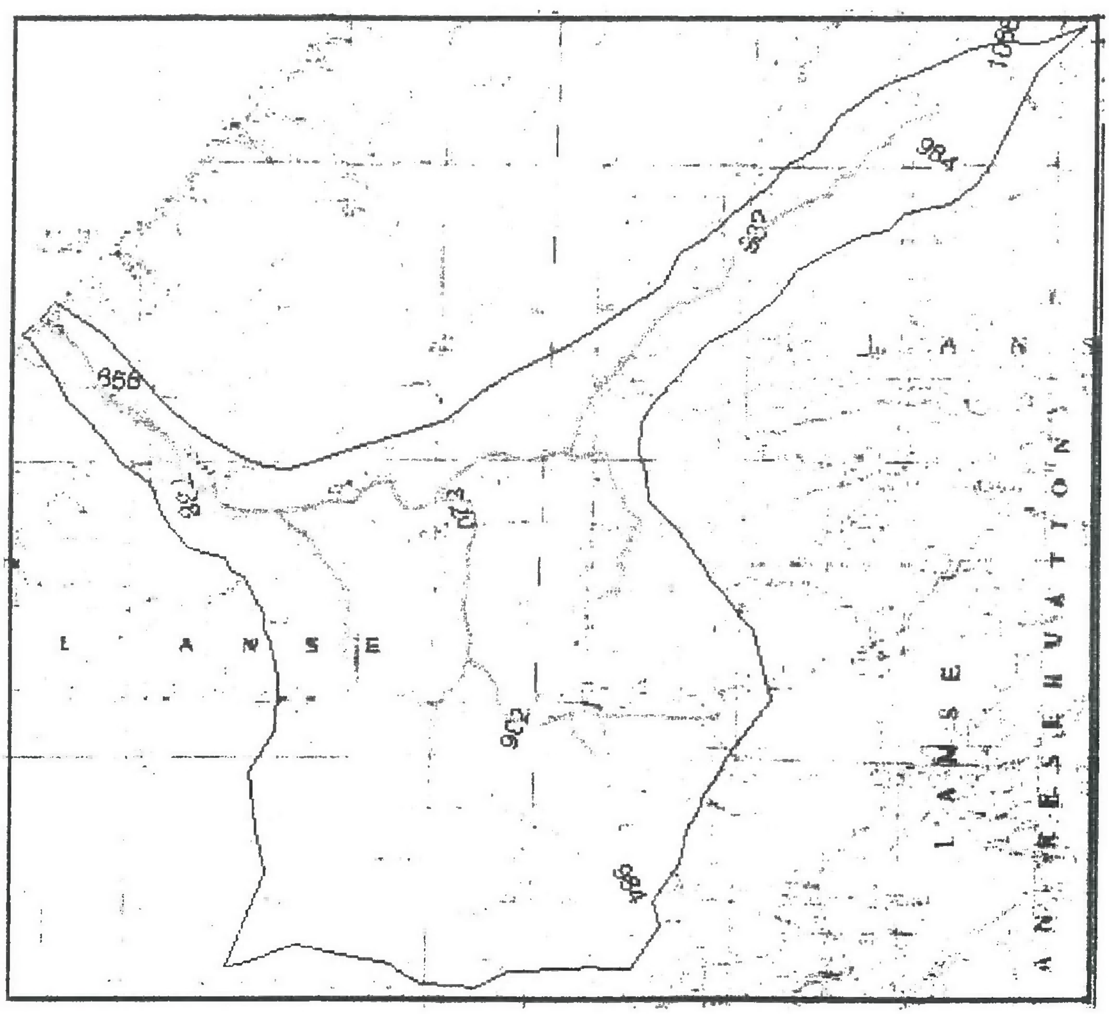

Figure 1. Outline of the Zeba (Little Silver) Creek watershed overlain on a U.S.G.S. topographic map. The orange lines represent the locations of Zeba Creek and its tributaries. The yellow contour lines depict contours generated from DEM data for the region. The contours are denoted by the elevation each represents in units of feet.

The analysis is performed on the watershed subdivided into an arrangement of rectangular grid elements that collectively approximate the areal attributes of the watershed and two layers reflecting the primary geologic formations of unconsolidated glacial drift overlying consolidated sandstone bedrock. The grid was designed to accurately represent the topographic elevations in the watershed, because we anticipate that the groundwater flow will follow the topography. The surface elevations from the DEM data correspond to areas of 101.628 ft by 101.628 feet, so the model grid was designed to match this resolution as shown in Figure 2.

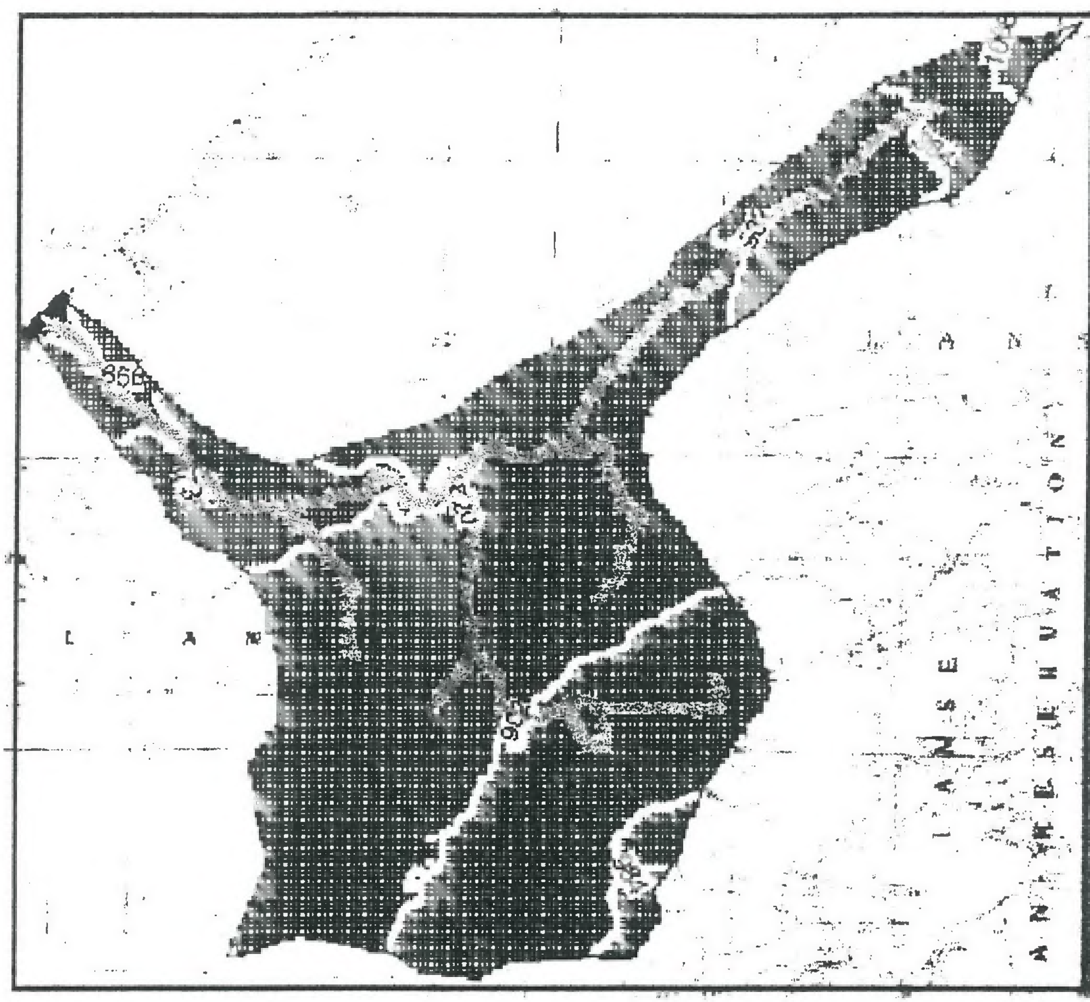

Figure 2. Schematic of the Zeba Creek watershed model grid. The cells are 100 by 100-feet square. Thicknesses vary depending on the topography and depth to bedrock. The orange line denotes the model cells that correspond to Zeba Creek and its tributaries. The yellow curves are topographic contours of surface elevation (feet amsl) for reference.

The modeling approach we are employing involves accounting for net precipitation less evapotranspiration, groundwater flows within the watershed boundaries but not across the boundaries, groundwater discharge into Lake Superior beneath the mouth of Zeba Creek (northwest extent of the watershed, and flows in Zeba Creek using a drain approximation as described below. To simulate the flows in the glacial deposits, a fine resolution grid is being employed, as shown in Figure 2. The glacial deposits are thin, but because of their relatively high permeability compared to the sandstone, the glacial drift is likely to conduct the majority of the flow. All of the tributaries to Zeba Creek are included in the model. Wetlands are not included explicitly, as the model should actually produce wetland conditions (*i.e.*, flooded conditions) in topographically low areas. This anticipated result will be used as one of the tests of the appropriateness of the model setup.

Water budgets are derived for each grid cell based on the interdependent processes depicted in Figure 3. Water-budget equations for each cell are related to the neighboring cells on the four sides and the cell vertically adjacent. The solution within a cell is influenced by the values of the neighbors, so the water-budget equations must be solved simultaneously for the entire grid.

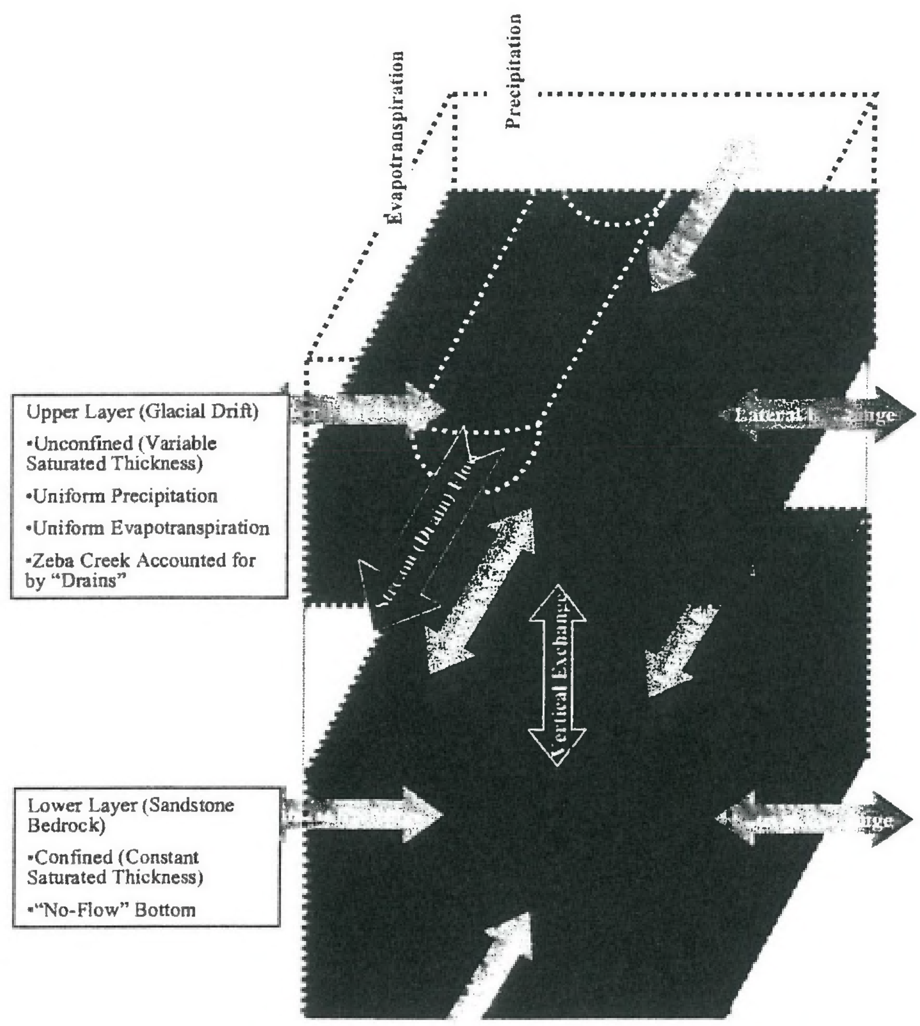

Figure 3. Schematic of model cells with components of the water budget s for the Zeba Creek Watershed.

To better understand how the watershed properties are incorporated into the model framework, an overview of the model equations applied to the Zeba Creek watershed are presented below. Much of the influence is apparent in how the different components are calculated. These influences are discussed in the context of each process represented in the waterbudget.

Water-Budget Equations

Glacial Drift (Upper Layer)

The steady-state, water-budget equation for each cell in the "upper" unconsolidated, glacial drift layer (k=1) is:

for each cell in row, i, column, j, layer, $k = 1$:

$$P_{i,j} \bullet A_{i,j}^{cell} - ET_{i,j} \bullet A_{i,j}^{cell} - Q_{i,j,1}^{stream} + Q_{i,j,1}^{lateral,N} + Q_{i,j,1}^{lateral,S} + Q_{i,j,1}^{lateral,E} + Q_{i,j,1}^{lateral,W} + Q_{i,j}^{vertical} = 0 \tag{1}$$

where:

i is the cell row number (the rows in the grid are oriented east-west),

j is the cell column number (the columns in the grid are oriented north-south),

k is the layer number (upper layer is 1 and lower layer is 2),

P is the *annual* precipitation (ft),

A^{cell} is the horizontal cell area (ft^2),

ET is the *annual* evapotranspiration (ft),

Q^{stream} is the *annual* flow of groundwater into the stream (ft^3),

$Q^{lateral}$ is the *annual* lateral flow of groundwater into adjacent cells along the North (N), South (S), West (W), and East (E) cell boundaries (ft^3), and

$Q^{vertical}$ is the *annual* vertical flow of groundwater between vertically adjacent cells (ft^3).

Sandstone Bedrock (Lower Layer)

The steady-state, water-budget equation for each cell in the "lower" sandstone bedrock layer (k=2) is:

$$\text{for each cell in row, } i, \text{ column, } j, \text{ layer, } k = 2:$$

$$Q_{i,j,2}^{lateral,N} + Q_{i,j,2}^{lateral,S} + Q_{i,j,2}^{lateral,E} + Q_{i,j,2}^{lateral,W} - Q_{i,j}^{vertical} = 0 \quad (2)$$

Water-Budget Components

Stream Flow (Q^{stream})

MODFLOW can simulate stream/groundwater interactions using 4 different approaches (cf. McDonald and Harbaugh (1988)). In our initial conceptualization, we have chosen to represent Zeba Creek as a series of "drains," which allows for stream flow only when the groundwater table is above the stream bottom (Figure 3) and is calculated using the following approach:

$$\text{for each cell}, i, j, k = 1:$$

$$Q_{i,j,1}^{stream} = \begin{cases} DCOND_{i,j} \bullet (h_{i,j,1} - d_{i,j}) & h_{i,j,1} > d_{i,j} \\ 0 & h_{i,j,1} \leq d_{i,j} \text{ or no drain condition for } i, j \end{cases} \quad (3)$$

where:

DCOND is a lumped "drain conductance" representing the combined processes of head losses through lower-permeability stream sediments and convergent flow from the surrounding aquifer into the stream (ft^2/yr),

h is the elevation of the groundwater table in the cell (ft), and

d is the elevation of the stream bottom (ft).

The approach used for a drain, as represented by Equation 3, allows flow of groundwater into Zeba Creek when the water table is above the stream bottom, otherwise the stream should be dry. Zeba Creek is dry in the upper reaches for most of the summer and so this may turn out to be an appropriate approximation for a small stream like Zeba Creek. A MODFLOW river boundary condition is probably not appropriate for predicting when the stream is dry, as the river stage must be specified as input. Of course, this drain approximation ignores surface run-off and interflow, which occurs over relatively short time periods during spring snow melt and after storms. The MODFLOW calculations of Zeba Creek flows (*i.e.*, the accumulation of the flows in the drain cells) compared to the measured flows should indicate the error in this approximation.

Lateral Groundwater Flow ($Q^{lateral}$)

Lateral groundwater flow between neighboring model cells is calculated using a conventional Darcy's Law approach:

$$\text{for each cell}, i, j, k:$$
$$Q_{i,j,k}^{lateral,a} = \begin{cases} RCOND_{i,j}^{N} \bullet (h_{i,j+1,k} - h_{i,j,k}) & \text{for } a = N \\ RCOND_{i,j}^{S} \bullet (h_{i,j-1,k} - h_{i,j,k}) & \text{for } a = S \\ CCOND_{i,j}^{E} \bullet (h_{i+1,j,k} - h_{i,j,k}) & \text{for } a = E \\ CCOND_{i,j}^{W} \bullet (h_{i-1,j,k} - h_{i,j,k}) & \text{for } a = W \end{cases} \tag{4}$$

where:

RCOND is the "row conductance," which includes the hydraulic conductivity and dimensional properties of the adjoining cells in the North-South direction (ft^2/yr), and

CCOND is the "column conductance," which includes the hydraulic conductivity and dimensional properties of the adjoining cells in the East-West direction (ft^2/yr).

In general, the conductances are calculated as the harmonic mean of the conductances of adjacent cells times the cross-sectional area between the cells divided by the distance between the cell centers. For a complete definition of the column and row conductances, refer to McDonald and Harbaugh (1988). The lateral groundwater flow is taken to be zero for the boundaries of outermost cells that coincide with the watershed boundaries.

Vertical Groundwater Flow ($Q^{vertical}$)

Vertical groundwater flow between model layers is also calculated using a conventional Darcy's Law approach:

$$\text{for each cell}, i, j, k = 1 \;\&\; 2:$$
$$Q_{i,j}^{vertical} = VCOND_{i,j} \bullet (h_{i,j,2} - h_{i,j,1}) \tag{6}$$

where:

> *VCOND* is the "vertical conductance," which includes the hydraulic conductivity and dimensional properties of the adjoining cells in both layers (ft^2/yr),

VCOND is calculated analogously to *RCOND* and *CCOND* described above. For a complete definition of the vertical conductance, refer to McDonald and Harbaugh (1988).

Precipitation (*P*)

Daily precipitation and temperature data is collected at a NOAA weather monitoring station in Herman, MI, which is 10 miles nearly due south of the Zeba Creek watershed, and at the KBIC Tribal Fish Hatchery, just over two miles Northeast from the mouth of Zeba Creek along Lake Superior. In addition a local resident (S. LaFernier) monitors precipitation daily from May through November at his property in the center of the watershed. Table 1 compares the observed precipitation amounts at the LaFernier residence to two nearby locations where daily observations of precipitation and temperature occur over the entire year and should be more reliable. The period of comparison is 15 June 1999 through 31 October 1999, which coincides with the first 4.5 months of observations by Ms. LaFernier. Variations in precipitation amounts seem to be influenced by elevation, i.e., more precipitation observed at locations of higher elevation. The Zeba Creek Watershed encompasses an elevation variation between 603 and 1150 ft amsl, but over 90% of the watershed area is between 730 and 980 ft amsl.

Table 1. Climate monitoring stations within the Zeba Creek Watershed (LaFernier) and nearby (Tribal Hatchery and Herman).

Location	**Latitude** (decimal degrees)	**Longitude** (decimal degrees)	**Elevation** (feet above mean sea level)	**Observed Precipitation** ***6/15/99 – 10/31/99*** (inches)
Herman (ID#203744)	46.67	88.35	1740	21.6
LaFernier Residence	46.80	88.37	919	17.3
Tribal Hatchery	46.84	88.38	627	14.0

Evapotranspiration (*ET*)

No measurements exist for evapotranspiration in this region and it was beyond our scope to develop field monitoring stations for *ET*. The empirical Thornthwaite method, which is commonly used to estimate potential and actual *ET* based on measured monthly precipitation and mean temperatures, was selected for this study. Ms. LaFernier does not monitor temperature and the observations are not as continuous as the Herman Weather Station and the Tribal Hatchery monitoring station. Since the Tribal Hatchery is closer to the Zeba Creek Watershed, its observations of monthly precipitation and mean monthly temperature were used in the Thornthwaite method, yielding an estimate of *ET* that was approximately 90% of the annual precipitation.

In our first modeling attempts, we are intending to simulate the steady-state conditions using annual average inputs and outputs to the watershed. Therefore the monthly variations in *ET* are not needed for the steady state analysis and so it is appropriate to account for *ET* by adjusting the precipitation amount (*P*) to represent a net precipitation (*P* – *ET*). Since precipitation data is lacking at other locations in the watershed, it is probably appropriate to use an average amount for net *P-ET* across the entire watershed.

Bedrock Topography

The primary activities in this work have been thus far aimed at obtaining the bedrock topography, because it will have a strong influence on the groundwater flow. Bedrock depths were obtained from drillers' logs, field reconnaissance (i.e., direct observations of outcrops), and geophysical surveys. The locations where bedrock information was obtained are depicted in Figure 4. The data from these locations were contoured in GMS to generate a bedrock topography map to delineate the boundary between the glacial drift and the bedrock in the model. The contours are shown in Figure 5. Unlike the surface topography, the bedrock topography is not adequate at this point for properly modeling the glacial drift/bedrock contact. This will be discussed further below.

Water Table Topography

Water table elevations for testing the model were obtained in April 2001 at the wells shown in Figure 6, denoted by the elevation of the water table in each well in units of feet amsl. The topography of the water table is being used to test the appropriateness of the model, so even though there is less data than for the bedrock, it is probably adequate. Also, the water table elevations vary less dramatically than the bedrock elevations.

Glacial Drift Thickness

The glacial drift thickness map depicts reasonable results where bedrock data exist, that is thicknesses vary from 10 to 30 feet, but where actual measurements are lacking and bedrock topography was obtained through interpolation of the measured bedrock elevations the resulting overburden thickness is either erroneously thin (the minimum by default is 1 foot) or erroneously thick in the southeast quadrant of the watershed. This result suggests more measurements of bedrock elevations are needed in the southern half of the watershed and in the vicinity of the main branch of Zeba Creek.

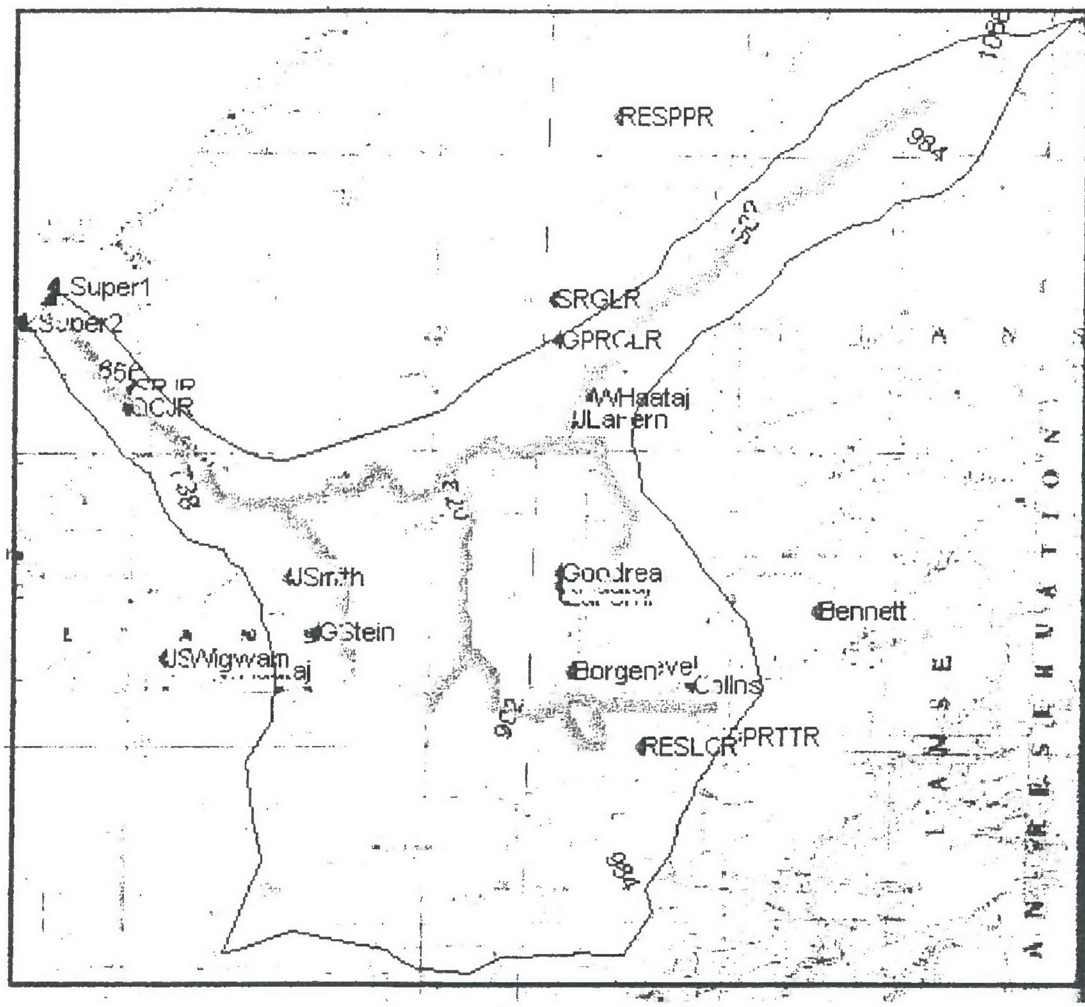

Figure 4. Map of the bedrock information in the Zeba Creek watershed. The labels are either an abbreviation of the well owners' names or a code (RES=resistivity, SRG=seismic reflection, GPR=ground-penetrating radar, OC=outcrop, LSuper=Lake Superior). The orange line denotes the model cells that correspond to Zeba Creek and its tributaries. The yellow curves are topographic contours of surface elevation (feet amsl) for reference.

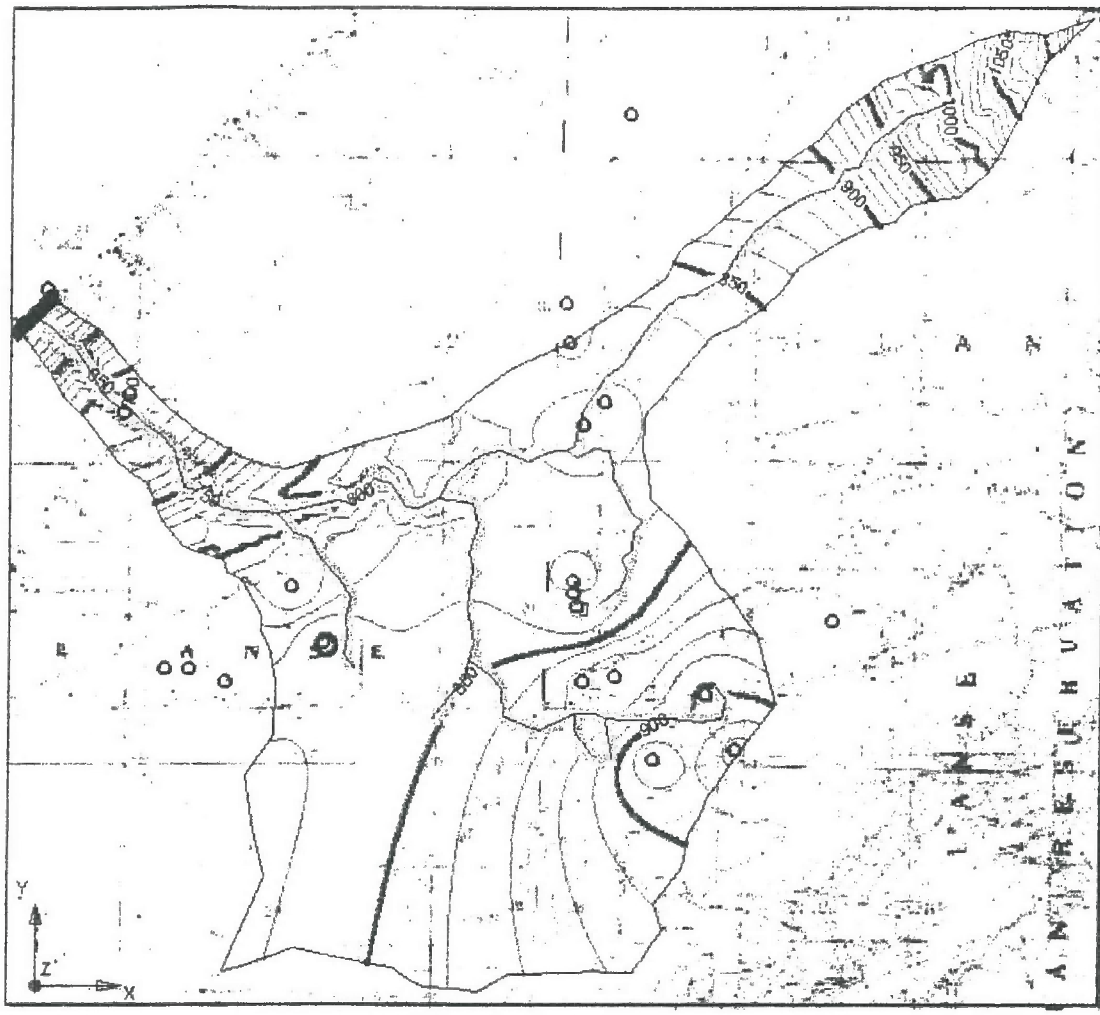

Figure 5. Bedrock contour map for the Zeba Creek watershed. The blue line denotes the Zeba Creek and its tributaries. The brown curves are bedrock elevation contours (feet amsl) derived from the bedrock observations denoted in Figure 4 and represented above in terms of the measured elevations.

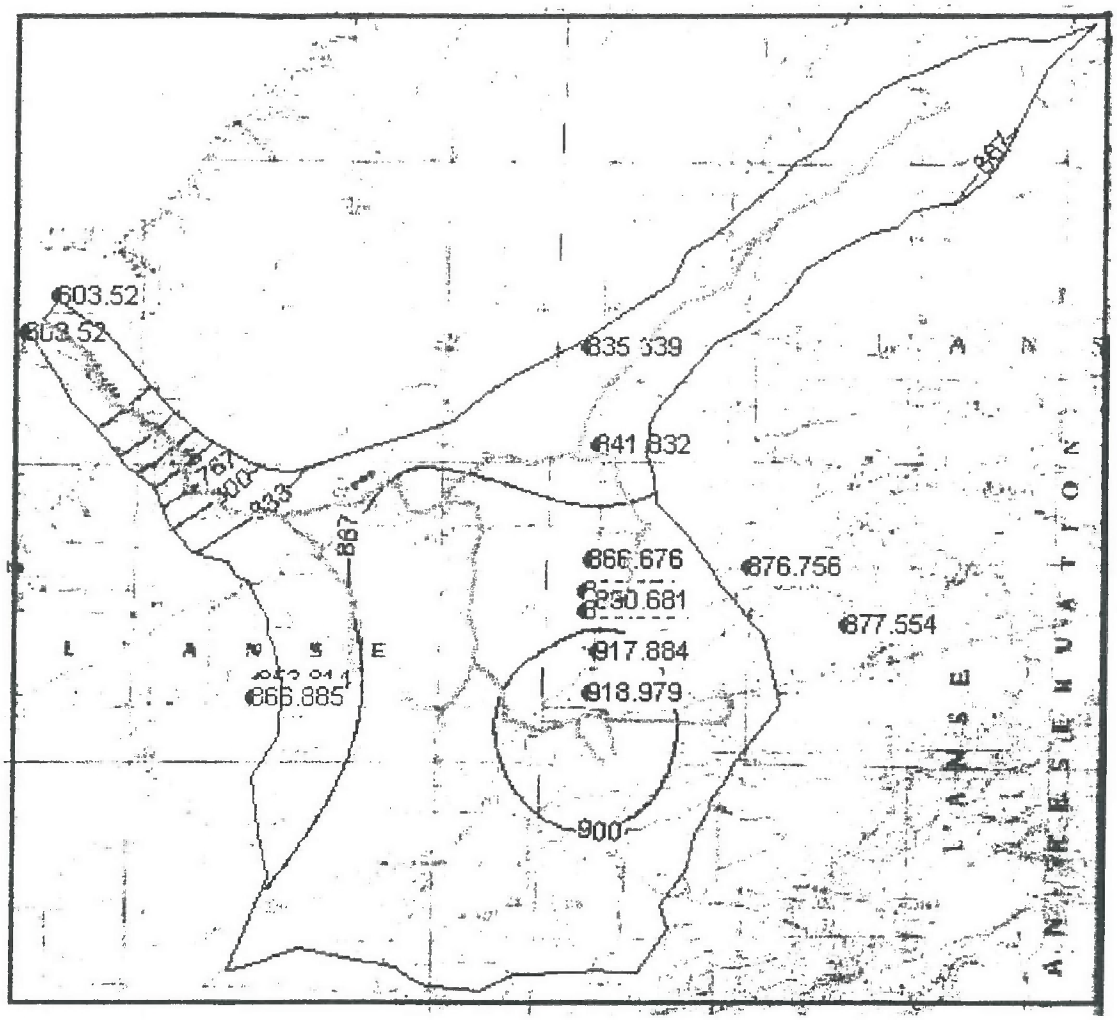

Figure 6. Water table elevation map derived from April 2001 water table monitoring..

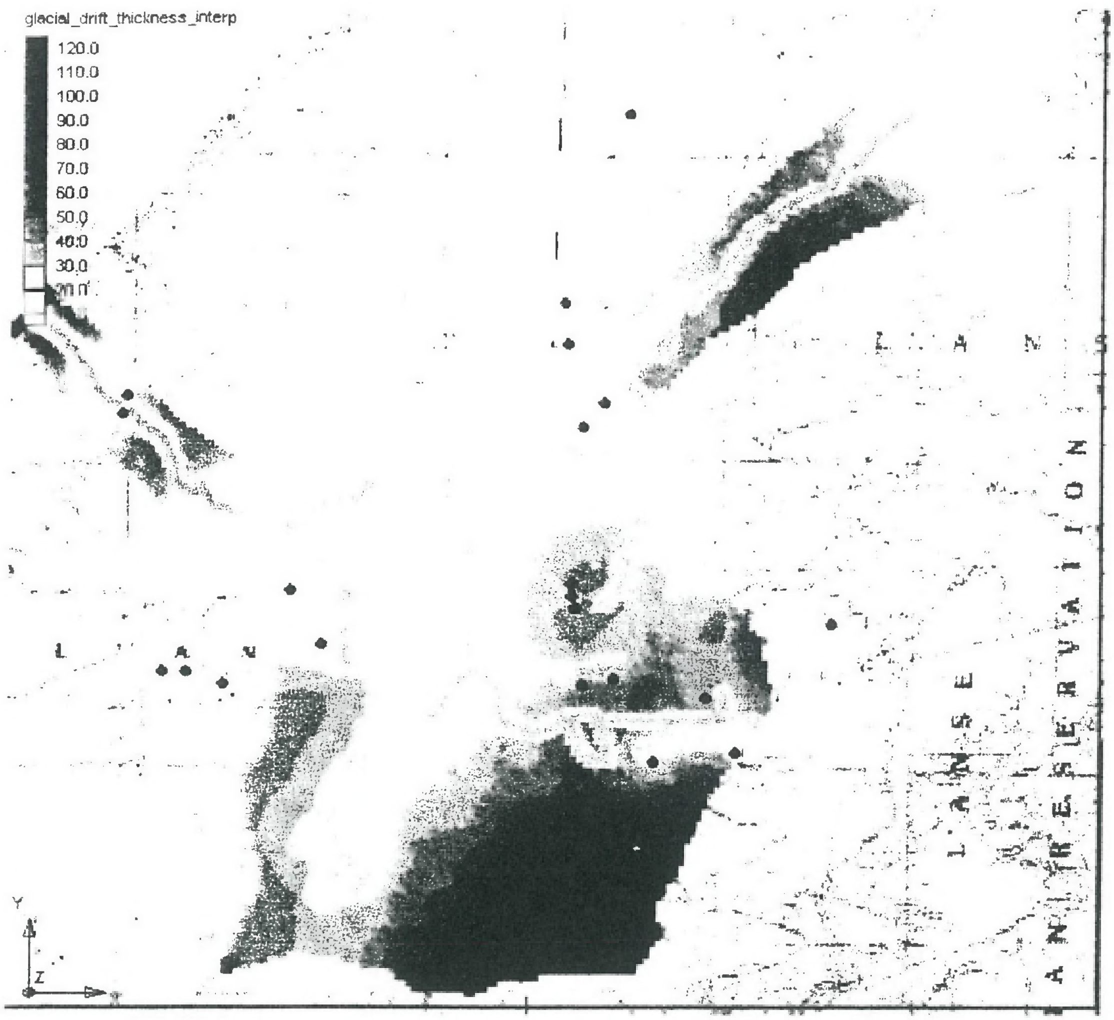

Figure 7. Glacial drift thickness map based on subtracting bedrock surface elevations (Figure 5) from surface elevations (Figure 1). The darker colors represent thicker glacial drift and white represents the minimum thickness (default) of one foot. The solid dots show locations for which the bedrock topography was derived. Surface topography was based on DEM data for 101-ft by 101-ft grid cells.

Plans and Recommendations

We have learned a lot so far in our collective efforts in characterizing and modeling the Zeba Creek Watershed; lessons that will help us successfully complete the modeling of the Zeba Creek Watershed as well as be more effective in our characterization of the neighboring Silver River Watershed and subsequent modeling efforts. Below is a summary of the lessons learned:

Lesson 1: It was too ambitious of us to expect to be able to characterize the geology of the watershed and develop a hydrological model in the same academic year. Now that we have experience in hydrogeological characterization, we should be able to perform the same characterization activities for the Silver River Watershed while continuing the model development and analysis of the Zeba Creek Watershed.

Lesson 2: Our field studies need to be planned more carefully to be more efficient and effective in a data collection and analysis. The fact that we now have nearly completed a complete iteration of characterization/modeling of the Zeba Creek Watershed means that we now have a clearer target of where and how to characterize the hydrogeology of the Silver River Watershed. Moreover, we should also be able to return to the Zeba Creek Watershed and collect data in areas where it is still needed.

Lesson 3: We need to be more considerate of reporting our progress and status.

Our plans are to:

1) Continue with the model development and testing of the Zeba Creek Watershed.

2) Begin characterization of the Bedrock topography and hydrogeology of the Silver River Watershed this fall.

3) Return to southern and northern sections of the Zeba Creek Watershed to measure bedrock depths in areas well wells are lacking and geophysical surveys have not yet been performed.

4) Submit end-of-month progress reports to Mr. Michael Duschene.

Aquifer Vulnerability Project Report for the Keweenaw Bay Indian Community Reservation and Encompassing Watersheds

Prepared by:
Inter-Tribal Council of Michigan, Inc.
Spring 2003

EXECUTIVE SUMMARY

The Inter-Tribal Council of Michigan, Inc (MITC) conducted the "Aquifer Vulnerability Project" to provide Keweenaw Bay Indian Community (KBIC) with information where the physical environment offers more or less groundwater protection in the vicinity of the L'Anse Indian Reservation. The geographic extent of the project was centered on KBIC's L'Anse Reservation in Baraga County, Michigan and extended to the outer boundaries of the Silver, Falls, Sturgeon, and Lake Drainage watersheds.

The premise of an aquifer vulnerability study is that the physical environment can provide different levels of aquifer protection depending on the depth and type of material in and around groundwater. This project utilized the DRASTIC methodology to assess aquifer vulnerability. DRASTIC evaluates the hydrogeologic variables affecting groundwater, including **D**epth to water, net **R**echarge, **A**quifer media, **S**oil media, **T**opographic slope, **I**mpact of the vadose zone, and hydraulic **C**onductivity. Depth, recharge, aquifer media, impact of the vadose zone, and hydraulic conductivity values were obtained from 604 sample wells and the geologic information contained in each well's log. Topographic slopes were derived from USGS Digital Elevation Models (DEMs) and soils information was derived from USDA soil type delineations. Each variable was ranked according to the extent to which it affects aquifer vulnerability as outlined in the attached matrix showing the DRASTIC ranking schemes. Following the ranking of sample location values, each hydrogeologic variable (depth, aquifer media, etc.) was weighted according to the extent to which it affects aquifer vulnerability.

The objective of the "Aquifer Vulnerability Project" was to produce a map showing varying aquifer vulnerability conditions in and around the Keweenaw Bay Indian Community to aid decision making. The following report states how aquifer vulnerability values were reached leaving the map to communicate the Project results.

DATA INVENTORIED AND ACQUIRED

The data necessary to conduct the "Aquifer Vulnerability Project" were obtained from a variety of sources. The first and largest inventory component of the Project began by collecting sample well locations that could be used to determine depth to water, recharge, aquifer media, impact of the vadose zone, and hydraulic conductivity throughout the Project area. Well information obtained from KBIC Natural Resources was a starting point for sample wells but many more wells were needed. The next step was to acquire the State's GIS coverage of wells in Baraga and Houghton counties provided by Michigan's Center for Geographic Information (MCGI). The preliminary well coverage can be downloaded from MCGI's website: *http://www.mcgi.state.mi.us/mgdl/?rel=thext&action=thmname&cid=2&cat=Drinking+Water+Wells*. In addition to the digital well logs, hardcopy well logs were obtained from the Michigan Department of Environmental Quality's (MDEQ) Wellogic database and their online archive of scanned well logs. The sources above comprise the origin of the sample wells used in the Project.

The second largest inventory component was the acquisition of soils data necessary for the DRASTIC evaluation. Neither Baraga nor Houghton counties had completed soils data in digital format in a scale suitable for the Project's scale. Soil Survey Geographic (SSURGO) data was a minimum of one year from completion. Further research concluded the only suitable digital soils data available for Baraga County was from the State of Michigan in Microstation design files in State Plane NAD27. The soils data for Baraga County was acquired from John Spitzley with MCGI. No digital soils data was available for Houghton County. The portion of the study area in Houghton County would require digitizing hardcopy soil delineations. Hardcopy soils maps of Houghton were requested from Glenn Lambert with the Natural Resource and Conservation Service.

The remainder of the digital spatial data was available for download from MCGI. Digital data acquired included digital elevation models (DEMs), public land survey boundaries, 1998 aerial photography, watershed boundaries, roads, streams, political boundaries, bedrock geology, and digital 1:24,000 topographic maps.

SPATIAL DATA COMPILATION AND STANDARDIZATION

Spatial data standardization began with geographically pinpointing sample wells from hardcopy format. Sample wells were located using township, range, section, quarter quarter section and/or address information printed on the well log. Aerial imagery was used in conjunction with the above information to locate each sample site. Only well logs with quality well location information and lithology were used. Geographically referenced hardcopy sample wells were merged with MCGI digital wells for Baraga and Houghton counties into one file and clipped to Project extent boundaries. A total of 604 sample wells were ultimately compiled within the sample well data layer.

Baraga soils were converted within ARC/INFO Workstation from Microstation soil quads in State Plane NAD27 to ArcView shapefiles. The quads were cleaned and merged into one file for Baraga County and reprojected into the Michigan Georef projection. The soil layer was then clipped to the Project's extent. The soil's attribute table was modified to contain the soil type as indicated in the Soil Survey of Baraga County Area, Michigan.

The Project contained a small area of land within Houghton County that had to have soil delineations digitized from two hardcopy maps. The soils were digitized using

ARC/INFO. The soil's attribute table was modified to contain the soil type as indicated in the Soil Survey of Houghton County Area, Michigan. The resulting soils layer was merged with the Baraga soils layer and cleaned for overlap and slivers. The final soils layer had good spatial integrity and was ready to be ranked and later converted to a raster layer for mathematical operations to be performed between layers.

Digital elevation models for Baraga and Houghton counties were converted from Interchange files to ARC/INFO GRIDS and were merged within ARC/INFO. The boundary between the two layers was cleaned to eliminate gaps. The resulting DEM was then clipped to the Project's extent. The layer was then ready to be ranked and undergo mathematical operations to be performed between layers.

The remainder of the acquired spatial data from MCGI was converted into ArcView shapefile format using ARC/INFO. The data was already in the Michigan Georef projection. The aforementioned spatial data was brought into an ARC/INFO 8.3 project for analysis and for cartographic output of analysis results.

CATEGORIZE/RANKING SPATIAL DATA ACCORDING TO AQUIFER VULNERABILITY

The following narrative describes how the seven hydrogeologic variables in the "Aquifer Vulnerability Project" using the DRASTIC methodology were ranked.

Depth to Aquifer

The Depth to Aquifer component of the Project was derived from the 604 sample wells located within the Project's boundaries. Each well was analyzed to determine the approximate depth of the groundwater from the surface. Calculating vulnerability for multiple aquifers at one sample locations was beyond the scope of this project. The groundwater targeted for vulnerability ranking was that being used by the well.

A majority of the wells within the Project's boundaries were rock wells developed in Jacobsville Sandstone or Michigamme Slate. Groundwater depths in these wells were assumed to be located at the static water level indicated on the well log or in some cases at the top of the Jacobsville Sandstone or Michigamme Slate. The top of the consolidated material was used in cases where the static water level was shallower than the top of the Jacobsville or Michigamme.

The depth to aquifer in the wells in unconsolidated material was calculated using the static water level in unconfined conditions. In wells that had confined groundwater, the depth of the bottom of the confining layer was used to measure depth to aquifer. Following the depth to aquifer determination for both rock and non-rock

DRASTIC Ratings for Depth to Water
(DRASTIC Weight 5)

Water table depth (feet)	DRASTIC rating
0-5	10
5-15	9
15-30	7
30-50	5
50-75	3

wells described above, the well was placed into one of the following depth to aquifer classifications.

Depth ranking values between wells were calculated by means of Spline interpolation. Spline estimates values using a mathematical function that minimizes overall surface curvature, resulting in a smooth surface that passes exactly through the input points. This method is best for gently varying surfaces such as elevation, water table heights, or pollution concentrations. There are two Spline methods: Regularized and Tension. The Tension method was used because it tunes the stiffness of the surface more closely to the character of the hydrogeologic conditions. It creates a less-smooth surface with values more closely constrained by the sample data range. For Tension, a weight parameter defines the amount of tension placed on the surface being created. The higher the weight, the coarser the surface. A tension weight of 15 was used in the depth to aquifer interpolation. The number of points used in the calculation of each interpolated cell was set at four sample wells. More input points would have caused interpolated cell values being more heavily influenced by distant wells. Finally, the cell size of the surface was set to the standardized 26.35 meter^2 to match that of the DEMs.

Recharge

Like the Depth to Aquifer component, Recharge was derived from analyzing each of the 604 sample well logs. Material in and above the groundwater at each sample location was studied to evaluate Recharge values. The consolidated material in the Project area is well cemented, has low permeability, and is generally confined according to the USGS (Groundwater Atlas of the United States Iowa, Michigan, Minnesota, Wisconsin HA 730-J – Jacobsville and crystalline-rock aquifers). Based upon the USGS assessment, rock wells were given the lowest recharge classification of 0-2 inches a year and assigned a value of 1 in DRASTIC.

Of the 604 sample wells, relatively few were set in unconsolidated material. Wells in the unconsolidated material were assigned the slightly higher classification of 2-4 inches a year based on the Project area's estimated average recharge of 2 inches a year. Few wells were estimated to have a moderately higher than average recharge based on relatively shallow depth and highly permeable overburden.

Recharge ranking values between sample locations were calculated by the same interpolation process described in the Depth to Aquifer narrative. A tension weight of 15 and values from four neighboring sample sites were used to calculate the value of each 26.35 meter^2 cell.

DRASTIC Ratings for Net Recharge (DRASTIC Weight 4)

Recharge (in/yr)	DRASTIC rating
0-2 (Jacobsville & Michigamme)	1
2-4	3
4-7	6
7-10	8
>10	9

Aquifer Media

Like the Depth to Aquifer and Recharge components, Aquifer media was derived from analyzing each of the 604 sample well logs. The process of determining aquifer media was performed in conjunction with the Depth to Aquifer step. Once the placement of groundwater was identified within a well log's lithology, the aquifer media according to the well driller was readily identifiable (i.e. sandstone, slate, sand, gravel, etc.). Overlay of well location with mapped bedrock types provided additional support for aquifer media determination. Jacobsville Sandstone was given a DRASTIC ranking value of 4 (DRASTIC: Massive Sandstone value range = 4-9). Jacobsville was given the least vulnerable ranking because of its high degree of consolidation. Michigamme Slate was given a DRASTIC ranking of 3 (DRASTIC: Metamorphic/igneous value range = 2-5). Michigamme Slate was given the average ranking for metamorphic/igneous consolidated material. The remaining aquifer media found in the Project area was fine sand, sand, and sand and gravel. These materials were ranked 6, 7, and 8 respectively according to the DRASTIC methodology.

DRASTIC Ratings for Aquifer Media
(DRASTIC Weight 3)

Aquifer material	DRASTIC rating
Massive shale	2 (1-3)
Metamorphic/igneous	3 (2-5)
Weathered metamorphic igneous	4 (3-5)
Glacial till	5 (4-6)
Bedded sandstone, limestone, shale	6 (5-9)
Massive sandstone	6 (4-9)
Massive limestone	6 (4-9)
Sand and gravel	8 (4-9)
Basalt	9 (2-10)
Karst, limestone	10

Aquifer Media ranking values between sample locations were calculated by the same interpolation process described in the Depth to Aquifer and Recharge narratives above. A tension weight of 15, values from four neighboring sample sites were used, and 26.35 meter^2 cells were created.

Soil Material

Soil Materials ranking values were derived from 1:24,000 USDA Soil Survey delineations and soil types. Each soil type was placed in a DRASTIC soil material category and assigned the corresponding DRASTIC rating shown to the right.

The Soil Material layer was based upon continuous 1:24,000 spatial data rather than interpolation between sample well locations performed with the first three hydrogeologic variables.

DRASTIC Ratings for Soil Media
(DRASTIC Weight 2)

Soil Material	DRASTIC rating
Thin or absent	10
Gravel	10
Sand	9
Peat	8
Shrinking and/or aggregated clay	7
Sandy loam	6
Loam	5
Silty loam	4
Clay loam	3
Muck	2
Nonshrinking and non-aggregated clay	1

Topographic Slope

Topographic Slope ranking values were derived from USGS digital elevations models (DEMs). Slope was calculated as a percent within ARC/INFO GIS. The resulting slope layer was reclassified according to established DRASTIC ratings found in the adjacent matrix.

The Topographic Slope layer was based upon continuous 1:24,000 spatial data rather than interpolation between sample well locations performed with the first three hydrogeologic variables.

DRASTIC Ratings for Topography
(DRASTIC Weight 1)

Slope (%)	DRASTIC rating
0-2	10
2-6	9
6-12	5
12-18	3
>18	1

Impact of the Vadose Zone

Like the Depth to Aquifer, Recharge, and Aquifer Media components of the Aquifer Vulnerability Project, Impact of the Vadose Zone was derived from analyzing each of the 604 sample well logs. The material in the vadose zone of each sample well was identified following the placement of groundwater within the well's lithology. The material that significantly characterized the unsaturated zone was ranked according to established DRASTIC values shown in the matrix to the right. In instances where more than one material made up the vadose zone, the material's rankings were averaged together to produce a final vadose zone value.

Impact of Vadose Zone ranking values between sample locations were calculated by the same interpolation process described in the Depth to Aquifer, Recharge, and Aquifer Media narratives above. A tension weight of 15, values from four neighboring sample sites were used, and 26.35 meter^2 cells were created.

DRASTIC Ratings for Vadose Zone
(DRASTIC Weight 5)
DRASTIC Ratings for Vadose Zone
(DRASTIC Weight 5)

Confining layer	1
Silt/clay	3 (2-6)
Shale	3 (2-5)
Limestone	6 (2-7)
Sandstone/Jacobsville	6/4 (4-8)
Bedded limestone, sandstone shale	6 (4-8)
Sand and gravel with significant silt & clay	4 (4-8)
Metamorphic/igneous	4 (2-8)
Sand and gravel	8 (6-9)
Basalt	9 (2-10)

Hydraulic Conductivity

The final hydrogeologic component evaluated by the Aquifer Vulnerability Project was the estimation and ranking of hydraulic conductivity. As with Depth to Aquifer, Recharge, Aquifer Media, and Impact of the Vadose Zone, Hydraulic Conductivity was derived from analyzing each of the 604 sample wells logs. The material identified in the Aquifer Media component was used to estimate hydraulic conductivity. The majority of wells were placed in Jacobsville Sandstone and Michigamme Slate. Jacobsville Sandstone was reported to have an estimated hydraulic conductivity of about 1 foot per day according to the USGS (Groundwater Atlas of the United States Iowa, Michigan, Minnesota, Wisconsin HA 730-J – Jacobsville and crystalline-rock aquifers). Michigamme Slate was assumed to have the same or less ability to transmit water according to well production reports (Water Resources of the Keweenaw Bay Indian Community, Baraga County, Michigan, 1998). Wells that were located in unconsolidated material were ranked according to the DRASTIC ranking scheme identified in the matrix to the right.

DRASTIC Ratings for Hydraulic Conductivity (DRASTIC Weight 3)

Conductivity (Meters/Day)	DRASTIC rating
<4 (Fine sand, clay, slate, jacobsville)	1
4-12 (Peat)	2
12-28 (Medium sand)	4
28-40 (Till)	6
40-80 (Coarse sand)	8
>80 (Gravel, fractured)	10

Hydraulic Conductivity ranking values between sample locations were calculated by the same interpolation process described in the Depth to Aquifer, Recharge, Aquifer Media, and Impact of the Vadose narratives above. A tension weight of 15, values from four neighboring sample sites were used, and 26.35 meter^2 cells were created.

DRASTIC Score/Aquifer Vulnerability

The aquifer vulnerability determination for the area within the Project boundary was a result of weighting (multiplying by weight shown in attached matrix) each hydrogeologic variable then overlaying each layer and getting a sum of the weighted DRASTIC rankings. The weights used to heighten the significance of one variable over another were a standard DRASTIC weighting scheme (seen in the equation below and in the attached matrix). The following equation was calculated within ARC/INFO GIS using each ranked hydrogeologic layer comprised of 26.35 meter^2 cells throughout the Project study area:

DRASTIC Score = $D_r * D_5 + R_r * R_4 + A_r * A_3 + S_r * S_2 + T_r * T_1 + I_r * I_5 + C_r * C_3$

The final step for mapping aquifer vulnerability within Keweenaw Bay Indian Community's reservation area was assigning each 26.35 meter^2 cell a qualitative risk. The qualitative risk categories used was the following commonly used DRASTIC classification: DRASTIC score 1-100 = Low aquifer vulnerability, DRASTIC score 101-140 = Moderate, DRASTIC score 141-200 = High, DRASTIC score >200 = Very High.

The resulting aquifer vulnerability/DRASTIC score and the seven hydrogeologic layers were printed on 17" X 11.5" paper at a scale of 1:150,000. The spatial data were stored and printed using the Michigan GeoRef projection. Copies of the digital spatial data were burned to compact discs for use by the Keweenaw Bay Indian Community.

Unfortunately by the late 1980s most agencies still had liberal creel limits on brook trout.

The Grand Portage Indian Reservation (Minnesota) and the U.S. Fish and Wildlife Service (USFWS) began a coaster management program on that reservation in the 1991. Early life history stages of the Nipigon strain were stocked into a few streams yielding returns in 1994. Beginning in 1989, management agencies instituted changes in bag limits and size limits to further protect "coaster" brook trout fisheries.

The Great Lakes Fishery Commission's (GLFC) Lake Superior Fish Community Objectives (Busiahn 1990) required the restoration of depleted stocks of native fish species including brook trout. The brook trout subcommittee under the GLFC Lake Superior Committee was established in 1993. That subcommittee completed a status paper in 1996 and a restoration plan in 1999. Various agencies have used these documents as a starting point for new coaster management in their jurisdictions. USFWS led another investigation at Isle Royale National Park in 1993. The first Isle Royale coaster strain from the Siskiwit River was established in 1995. Year classes from Tobin Harbor at Isle Royale were established in 1996, 1998, and 2001. USFWS has continued annually worked with Isle Royale "coaster" brook trout. USFWS and Keweenaw Bay Indian Community started stocking the Siskiwit River progeny in 1998 near Keweenaw Bay. The Pictured Rocks National Park streams were also first stocked at the same time. The Iron River National Fish hatchery maintains these Isle Royale coaster strains, while OMNR Dorian Hatchery and Red Cliff Indian Hatchery have Nipigon strains of brook trout. Ongoing genetic research is still trying to answer the question of what is a coaster? U.S. Geological Survey, USFWS, and University of Minnesota are attempting to isolate genetic markers specific for coasters. During the last decade, USFWS and Tout Unlimited have shared educational materials with the public.

The collective agencies have demonstrated a variety of management approaches for their respective brook trout fisheries over the last 150 years. Early years resulted in destruction of habitat and overharvest of this species. Today, few remnant populations exist in Nipigon area and other zones of Ontario as well as Isle Royale National Park and Salmon Trout River of Michigan. The Great Lakes Fishery Commission and American Fisheries Society have sponsored forums to exchange ideas and research on coaster brook trout. Ontario, Michigan, Minnesota, and Wisconsin have renewed their focus on coaster brook trout management. The Native American communities of Grand Portage, Red Cliff, and Keweenaw Bay have promoted experimental management on their reservations. The USFWS and Trout Unlimited have provided educational material on the unique aspects of coaster brook trout. The prognosis is positive for sustained populations in selected areas around Lake Superior.

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MICHIGAN DEPARTMENT OF ENVIRONMENTAL QUALITY
SURFACE WATER QUALITY DIVISION
JANUARY 2002

STAFF REPORT

A BIOLOGICAL SURVEY OF THE STURGEON RIVER WATERSHED AND NINE OTHER LAKE SUPERIOR COASTAL WATERSHEDS IN BARAGA COUNTY BARAGA AND HOUGHTON COUNTIES, MICHIGAN JULY 2001

INTRODUCTION

As part of the environmental assessment program, staff of the Great Lakes and Environmental Assessment Section (GLEAS) investigated the biological integrity and physical habitat conditions of the Sturgeon River and nine other Lake Superior coastal watersheds within Baraga County. This investigation involved performing qualitative biological surveys using GLEAS Procedure # 51 (SWQD 1997, 1998) (available upon request), at 20 stations and visually assessing water quality and physical habitat conditions at 4 stations. Water samples were also collected and transported to the Michigan Department of Environmental (DEQ) lab for chemical analysis.

Biological Survey Objectives

The survey activities within the Sturgeon River Watershed and Baraga County Lake Superior Watersheds were conducted to: 1) qualitatively evaluate the current biological and physical conditions of selected stream segments, 2) evaluate general water quality within the watershed, 3) evaluate attainment status with Michigan's Water Quality Standards, and 4) identify possible sources of nonpoint source pollution problems and evaluate the effectiveness of nonpoint source water quality improvement projects.

Watershed Characteristics

The Sturgeon River Watershed is located in Baraga and Houghton counties in the northwestern part of the Upper Peninsula and is a tributary to Portage Lake. Baraga County coastal watersheds were also monitored, including watersheds from Kelsey Creek to the Ravine River. The watersheds are located in the Northern Lake and Forest ecoregion. This region is dominated by light agriculture, forested land on sandy soils, and much of the region is located within the Keweenaw Bay Indian Reservation. The major sectors of the economy include manufacturing, particularly durable goods, the service sector, primarily the tourism industry, and the governmental sector because of a correctional facility. Less than 10 percent of the land in this region is farmed, and that portion is comprised mostly of livestock and orchards. The agricultural sector of the economy is small, but is still an important part of the community and adds to the scenic landscapes in the region. In addition, the only significant point source discharge within the region is the L'Anse WWTP, which discharges to Linden Creek in L'Anse. In general, the streams in this area are high quality coldwater streams with stable substrate and good macroinvertebrate communities. Nonpoint source pollution is not expected to be a large problem and there are not currently any Clean Michigan Initiative or Section 319 grant supported water quality protection/improvement projects.

The largest watershed in the region is the Sturgeon River Watershed which begins in Baraga County and continues through the eastern edge of Houghton County before it enters Portage Lake. The Sturgeon River has several tributaries including Tioga River, Pelkie Creek, Rock River, Kelsey Creek, Perch River, and Sidnaw Creek, which are located in the headwaters of the watershed. Below Prickett Dam the Silver River and the West Branch Sturgeon River converge with the Sturgeon River.

The remaining watersheds in Baraga County are comprised of coastal Lake Superior Watersheds of varying watershed size. The rivers monitored in this survey include Kelsey Creek (note there is also a Kelsey Creek in the Sturgeon River Watershed), Little Carp River, Hazel Creek, Menge Creek, Falls River, Linden Creek, Kalio Creek, Silver River (note there is also a Silver River in the Sturgeon River Watershed), Slate River, and Ravine River. The Sturgeon River Watershed and the Baraga County coastal watersheds are coldwater systems and designated trout streams (MDNR 1994).

Previous biological surveys in these watersheds include studies on Linden Creek upstream and downstream of the L'Anse WWTP (Taft 1994; Suppnick 1997) and Menge Creek (Taft 1995). Taft (1994) found a direct impact of the L'Anse WWTP on the biota of the Linden Creek, which may have been due to high levels of total residual chlorine in the WWTP effluent. Suppnick (1997) found that dissolved oxygen and pH standards were being met throughout the summer of 1995. On Menge Creek, Taft (1995) found physical habitat conditions were being impacted by sedimentation from logging activities and beaver dams.

Biological Survey Stations

A map of the watershed identifying the 20 biological survey stations, 4 station visits, and 13 water chemistry stations evaluated in this study is presented in Figure 1. A description of each station is provided in Table 1 and additional habitat evaluation and location information for each biological survey station is presented in Table 2 and described below.

In-Stream and Streamside Habitat Status

Habitat was assessed at 20 stations in this watershed survey. Stations 1-5, 9, 12, 14, 15, and 17-19 were rated as having excellent habitat, Stations 6, 7, 10, 11, 13, and 20 were rated good and stations 8 and 16 were rated fair (Table 2). Stations 8 and 16, on Silver River and Linden Creek respectively, were rated as having fair habitat due to the low scores for bottom substrate/available cover and bottom deposition. The Silver River runs through a region dominated by sandy soils and the deposition in the stream occurs naturally. Both rivers have some woody debris in the channel providing macroinvertebrate habitat, however it was more extensive in the Silver River possibly as a result of its extensively vegetated riparian zone. The riparian area on Linden Creek downstream of the WWTP parallels Dickenson Road and only has a narrow grass/shrub buffer between the road and the stream. Linden Creeks narrow width and depth also limit the amount of woody debris accumulation that can occur within the stream. There is some evidence that the culverts on Linden Creek in L'Anse need improvement and are currently trapping sediment.

The remaining 18 stations evaluated in this survey were all classified as having good or excellent habitat. The upper reaches of the Sturgeon River watershed (Stations 1-6) all had extremely stable substrate, extensive macroinvertebrate habitat, and stable flow and bank vegetation. The dominant substrate in these streams was cobble and boulder. The lower reaches of the Sturgeon River watershed are much sandier, often with little stable substrate besides woody debris. The Lake Superior coastal watersheds in Baraga County show a range of habitat. The headwaters of many of the watersheds are rocky, high gradient streams with excellent riparian vegetation. Closer to the mouths, the rivers were often sandier and sometimes their flows were backed up at the confluence with Lake Superior. Hazel Creek and the Little Carp River (Stations 21 and 22, respectively) were almost stagnant at the river mouth, but had good flow and habitat upstream (Station 23 and 11, respectively.) Streamside vegetation in the watersheds is comprised of shrubs, trees, and grasses and all three vegetation types are often found at one station.

Potential nonpoint/erosion control issues were observed in the headwaters of Menge Creek and near the mouth of the Slate River. Extensive sedimentation was observed in Menge Creek at the snowmobile crossing upstream of Menge Creek Road. Taft (1995) attributed sedimentation problems on Menge Creek to logging activities and beaver dams. Upstream of the Silver Road crossing of the Slate River, Arvon Road runs parallel to the Slate River and has extensive erosion along both sides of the road (Figure 2). After a storm event, sheet flow was observed carrying large amounts of sediment from Arvon Road through a forested area and into the Slate River.

Macroinvertebrate Community Status

The macroinvertebrate community was assessed at 20 of the 24 stations in this survey (macroinvertebrates were not fully assessed at stations 21-24). Stations 1, 7-12, 15, 16, and 18-20 were rated as acceptable, while stations 2-6, 13, 14, and 17 were rated as excellent (Tables 3A and 3B). Overall, the stream macroinvertebrate communities in this area are in very good condition and indicate high quality water. Many of the stations with acceptable ratings had scores of 3 or 4, which are just under the cut off for an excellent rating which is 5. The number of taxa found at each station varied between 18 and 38 taxa, however at most stations more than 24 taxa were collected. At stations 4, 8, and 16, fewer than 24 taxa were collected due to sandy substrates.

Station 16 is located downstream of the L'Anse WWTP and only 18 macroinvertebrate taxa were collected here. In addition, over 70 percent of the organisms collected at Station 16 were from the order Diptera (Athericidae, Ceratopogonidae, Chironomidae, and Simuliidae). Upstream of the WWTP (station 15) there was much more macroinvertebrate diversity and 28 macroinvertebrate taxa were collected. Although both stations rated as having acceptable macroinvertebrate communities, station 15 scored a 3 and station 16 scored a -3 (values on the ends of the range for the acceptable rating which covers scores from -4 to 4). Although the stations are upstream and downstream of the WWTP, habitat seems to be responsible for the reduced macroinvertebrate community at station 16 rather than WWTP effluent quality. At station 15, Linden Creek has a gravel, cobble, and sand substrate, extensive bends, flow and depth variability, and woody debris. This habitat can support a more diverse macroinvertebrate community than the habitat found at station 16.

Throughout the rest of the watershed most stations had relatively diverse communities and the dominant taxa comprised less than 20 percent of the individuals collected. Again station 16, located downstream of the L'Anse WWTP, was an anomaly and the dominant taxa (Ceratopogonidae in the order Diptera) represented 35 percent of the organisms collected at the station. At all of the stations at least one mayfly, caddisfly, and stonefly was collected and the majority of stations had a large number of families from each of these orders. All stations had less than 10 percent of the macroinvertebrate community comprised of isopods, snails, and leeches and less than 11 percent of the community were airbreathing taxa indicating well oxygenated stream environments.

Fish Community Status

Fish community data were only collected at stations 15 and 16 (Tables 4A, 4B), upstream and downstream of the L'Anse WWTP on Linden Creek. Salmonids were collected in abundance at both stations with small rainbow trout being the most common fish collected. At station 16, some larger rainbow trout were collected along with brook trout and brown trout. Sculpins were the only other fish taxa collected on Linden Creek. The presence of multiple trout species downstream of the WWTP provides further evidence that the low macroinvertebrate score observed at this station is due to reduced habitat quality, instead of effluent quality.

Water Chemistry

Water chemistry samples were taken at fourteen stations within the watershed, including Stations 2, 7-9, 11, 13-17, and 20-23. Overall, nutrients monitored at all of the stations besides the station downstream of L'Anse WWTP (Station 16) were within the range of values seen in undeveloped stream basins across Michigan (Clark et al. 2000). Total phosphorus concentrations ranged from 0.01 to 0.037 mg/l, except for downstream of the WWTP (Station 16) where the concentration was 0.19 mg/l. Ammonia and kjeldahl nitrogen concentrations were also elevated at Station 16 at 1.2 and 1.9 mg/l, respectively. In addition, no toxic chemicals were detected at any station at levels that exceeded their respective Rule 57 water quality values.

Michigan Water Quality Standard Attainment Status

Good habitat, fish community, and macroinvertebrate community scores, combined with the water chemistry analyses, indicate the Sturgeon River and the other nine Lake Superior coastal watersheds in Baraga County are meeting the requirements of the Michigan Water Quality Standards. However, it may be possible to further improve the habitat and biological communities in these streams by implementing additional best management practices to reduce the erosion of sediment.

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Field work by: Sarah Walsh, Aquatic Biologist
Dawn Roush, Aquatic Biologist

Report by: Sarah Walsh, Aquatic Biologist
Great Lakes and Environmental Assessment Section

Table. 1. Station locations of macroinvertebrate, habitat, fish, and site visits surveys in the Sturgeon River and Baraga County coastal watersheds, July 2001.

STATION	WATER BODY	LOCATION	LATITUDE	LONGITUDE	HABITAT	BUGS	FISH	WATER	SITE VISIT
1	Tioga Cr	US 41	46.57512	-88.34029	X	X			
2	Sturgeon River	Dirt Rd off US-41	46.61440	-88.45203	X	X		X	
3	Rock River	US 141	46.57286	-88.49391	X	X			
4	Kelsey Cr	Plains Rd	46.55836	-88.57404	X	X			
5	Perch River	US 28	46.51822	-88.66312	X	X			
6	Sidnaw Cr	Pequot Lake Rd	46.54652	-88.73064	X	X			
7	Sturgeon River	Forest Hwy	46.66991	-88.72034	X	X		X	
8	Silver River	M 38	46.76258	-88.69504	X	X		X	
9	W B Sturgeon	Hazel	46.78418	-88.72120	X	X		X	
10	W B Sturgeon	Pine River Rd	46.80687	-88.63698	X	X			
11	Little Carp River	Bear Town Rd	46.81138	-88.52008	X	X		X	
12	Kelsey Cr	US 42	46.87722	-88.47788	X	X			
13	Menge Cr	Menge Cr Rd	46.74594	-88.49741	X	X		X	
14	Falls River	Mead Rd	46.72971	-88.44411	X	X		X	
15	Linden Ck	u/s of L'anse WWTP	46.76039	-88.44550	X	X	X	X	
16	Linden Ck	d/s of L'anse WWTP	46.75857	-88.45110	X	X	X	X	
17	Silver River	Skanee Rd	46.80424	-88.31756	X	X		X	
18	Kalio Cr	Skanee Rd	46.80204	-88.33320	X	X			
19	Slate River	Silver Rd	46.80888	-88.23090	X	X			
20	Ravine River	Sicotte Rd	46.83797	-88.21383	X	X		X	
21	Little Carp River	US41	46.83545	-88.48348				X	X
22	Hazel Creek	US41	46.75851	-88.50038				X	X
23	Hazel Creek	upstream						X	
24	Green Creek	Newberry Rd							X

e 2A. Habitat evaluation for the Sturgeon River and Baraga County watersheds, July 2001.

HABITAT METRIC (MAX)	STATION 1 Tioga Cr US 41	STATION 2 Sturgeon River Dirt Rd off US-41	STATION 3 Rock River US 141	STATION 4 Kelsey Cr Plains Rd	STATION 5 Perch River US 28
Bottom Substrate Avail. Cover (20):	16	20	20	20	20
Embeddedness (20):	19	18	19	20	16
Velocity:Depth (20):	15	15	19	17	20
Flow Stability (15):	13	15	14	10	14
Bottom Depos. (15):	14	13	15	10	10
Pools-Riffles-Runs-Bends (15):	11	11	15	11	14
Bank Stability (10):	10	10	10	9	9
Bank Vegetative Stability (10):	10	10	10	10	10
Stream Cover (10):	5	8	6	6	7
TOTAL SCORE (135):	113	120	128	113	120
ABITAT RATING:	EXCELLENT (NON-IMPAIRED)	EXCELLENT (NON-IMPAIRED)	EXCELLENT (NON-IMPAIRED)	EXCELLENT (NON-IMPAIRED)	EXCELLENT (NON-IMPAIRED)

Date:	7/11/2001	7/11/2001	7/12/2001	7/12/2001	7/12/2001
Weather:	Sunny	Sunny	Sunny	Sunny	Sunny
Air Temperature:	70 Deg. F.	65 Deg. F.	71 Deg. F.	72 Deg. F.	75 Deg. F.
Water Temperature:	0 Deg. F.	0 Deg. F.	0 Deg. F.	0 Deg. F.	67.5 Deg. F.
Ave. Stream Width:	15 Feet	20 Feet	15 Feet	6 Feet	18 Feet
Ave. Stream Depth:	0.5 Feet	0.666 Feet	0.5 Feet	0.25 Feet	0.8 Feet
Surface Velocity:	1 Ft./Sec.	0.8 Ft./Sec.	1 Ft./Sec.	1.5 Ft./Sec.	1 Ft./Sec.
Estimated Flow:	7.5 CFS	10.656 CFS	7.5 CFS	2.25 CFS	14.4 CFS
STORET No.:	70070	70071	70072	70073	70074
Stream Name:	Tioga Cr	Sturgeon River	Rock River	Kelsey Cr	Perch River
Road Crossing/Location:	US 41	Dirt Rd off US-41	US 141	Plains Rd	US 28
County Code:	07	07	07	07	07
TRS:	48N32W08	49N33W29	48N34W12	48N34W16	48N35W34
Latitude (dd):	46.57512	46.6143992	46.57286	46.55836	46.51822
Longitude (dd):	-88.34029	-88.4520308	-88.49391	-88.57404	-88.66312
Ecoregion:	NLAF	NLAF	NLAF	NLAF	NLAF
Stream Type:	Coldwater	Coldwater	Coldwater	Coldwater	Coldwater
USGS Basin Code:	4020104	4020104	4020104	4020104	4020104

COMMENTS:

Table 2B. Habitat evaluation for the Sturgeon River and Baraga County watersheds, July 2001.

HABITAT METRIC (MAX)	STATION 6 Sidnaw Cr Pequot Lake Rd	STATION 7 Sturgeon River Forest Hwy	STATION 8 Silver River M 38	STATION 9 W B Sturgeon Hazel Rd	STATION 10 W B Sturgeon Pine River Rd
Bottom Substrate Avail. Cover (20):	18	5	6	17	8
Embeddedness (20):	14	11	10	11	11
Velocity:Depth (20):	18	11	10	20	11
Flow Stability (15):	13	15	12	15	15
Bottom Depos. (15):	10	4	7	10	5
Pools-Riffles-Runs-Bends (15):	11	8	6	15	8
Bank Stability (10):	8	8	4	9	8
Bank Vegetative Stability (10):	9	9	9	10	9
Stream Cover (10):	5	6	6	8	5
TOTAL SCORE (135):	106	77	70	115	80
HABITAT RATING:	GOOD (SLIGHTLY IMPAIRED)	GOOD (SLIGHTLY IMPAIRED)	FAIR (MODERATELY IMPAIRED)	EXCELLENT (NON-IMPAIRED)	GOOD (SLIGHTLY IMPAIRED)
Date:	7/12/2001	7/14/2001	7/13/2001	7/13/2001	7/14/2001
Weather:	Sunny	Partly Cloudy	Sunny	Sunny	Sunny
Air Temperature:	78 Deg. F.	78 Deg. F.	75 Deg. F.	75 Deg. F.	80 Deg. F.
Water Temperature:	67.1 Deg. F.	68 Deg. F.	73.8 Deg. F.	67.1 Deg. F.	74.3 Deg. F.
Ave. Stream Width:	12 Feet	40 Feet	12 Feet	22 Feet	15 Feet
Ave. Stream Depth:	0.666 Feet	2 Feet	0.666 Feet	0.5 Feet	0.83 Feet
Surface Velocity:	0.75 Ft./Sec.	0.4 Ft./Sec.	0.5 Ft./Sec.	1 Ft./Sec.	1 Ft./Sec.
Estimated Flow:	5.994 CFS	32 CFS	3.996 CFS	11 CFS	12.45 CFS
STORET No.:	310383	310386	310385	310384	70077
Stream Name:	Sidnaw Cr	Sturgeon River	Silver River	W B Sturgeon	W B Sturgeon
Road Crossing/Location:	Pequot Lake Rd	Forest Hwy	M 38	Hazel Rd	Pine River Rd
County Code:	31	31	31	31	07
TRS:	48N35W19	49N35W06	50N35W04	51N35W27	51N35W20
Latitude (dd):	46.54652	46.66991	46.76258	46.78418	46.80687
Longitude (dd):	-88.73064	-88.72034	-88.69504	-88.7212	-88.63698
Ecoregion:	NLAF	NLAF	NLAF	NLAF	NLAF
Stream Type:	Coldwater	Coldwater	Coldwater	Coldwater	Coldwater
USGS Basin Code:	4020104	4020104	4020005	4020104	4020104

COMMENTS:

le 2C. Habitat evaluation for the Sturgeon River and Baraga County watersheds, July 2001.

HABITAT METRIC (MAX)	STATION 11 Little Carp River Bear Town Rd	STATION 12 Kelsey Cr US 41	STATION 13 Menge Cr Menge Cr Rd	STATION 14 Falls River Mead Rd	STATION 15 Linden Creek u/s L'anse WWTP
Bottom Substrate Avail. Cover (20):	18	18	11	20	16
Embeddedness (20):	14	16	12	16	15
Velocity:Depth (20):	17	15	15	14	20
Flow Stability (15):	10	13	14	15	15
Bottom Depos. (15):	11	11	8	10	9
Pools-Riffles-Runs-Bends (15):	8	11	9	11	13
Bank Stability (10):	7	10	9	10	7
Bank Vegetative Stability (10):	9	10	9	10	8
Stream Cover (10);	7	7	6	8	6
TOTAL SCORE (135):	101	111	93	114	109
ABITAT RATING:	GOOD (SLIGHTLY IMPAIRED)	EXCELLENT (NON-IMPAIRED)	GOOD (SLIGHTLY IMPAIRED)	EXCELLENT (NON-IMPAIRED)	EXCELLENT (NON-IMPAIRED)

Date:	7/17/2001	7/13/2001	7/16/2001	7/15/2001	7/17/2001
Weather:	Cloudy	Sunny	Cloudy	Rainy	Sunny
Air Temperature:	62 Deg. F.	60 Deg. F.	65 Deg. F.	65 Deg. F.	72 Deg. F.
Water Temperature:	63.5 Deg. F.	59.9 Deg. F.	58.6 Deg. F.	62.6 Deg. F.	62.1 Deg. F.
Ave. Stream Width:	7 Feet	7 Feet	8 Feet	12 Feet	11 Feet
Ave. Stream Depth:	0.4166 Feet	0.3 Feet	0.5 Feet	1 Feet	0.666 Feet
Surface Velocity:	0.5 Ft./Sec.	0.5 Ft./Sec.	1.25 Ft./Sec.	1.2 Ft./Sec.	1.2 Ft./Sec.
Estimated Flow:	1.4581 CFS	1.05 CFS	5 CFS	14.4 CFS	8.7912 CFS
STORET No.:	70080	70075	70081	70078	70084
Stream Name:	ittle Carp River	Kelsey Cr	Menge Cr	Falls River	Linden Creek
Road Crossing/Location:	Bear Town Rd	US 41	Menge Cr Rd	Mead Rd	u/s L'anse WWTP
County Code:	07	07	07	07	07
TRS:	51N34W17	51N33W10	50N34W12	50N33W16	50N33W05
Latitude (dd):	46.81138	46.87722	46.74594	46.72971	46.76039
Longitude (dd):	-88.52008	-88.47788	-88.49741	-88.44411	-88.4455
Ecoregion:	NLAF	NLAF	NLAF	NLAF	NLAF
Stream Type:	Coldwater	Coldwater	Coldwater	Coldwater	Coldwater
USGS Basin Code:	4020105	4020105	4020105	4020105	4020105

COMMENTS:

'Table 2D. Habitat evaluation for the Sturgeon River and Baraga County watersheds, July 2001.

HABITAT METRIC (MAX)	STATION 16 Linden Creek d/s L'anse WWTP	STATION 17 Silver River Skanee Rd	STATION 18 Kalio Cr Skanee Rd	STATION 19 Slate River Silver Rd	STATION 20 Ravine River Sicotte Rd
Bottom Substrate Avail. Cover (20):	6	20	18	18	17
Embeddedness (20):	11	16	16	16	11
Velocity:Depth (20):	10	19	18	17	10
Flow Stability (15):	11	14	10	14	12
Bottom Depos. (15):	3	10	12	12	8
Pools-Riffles-Runs-Bends (15):	5	15	12	12	9
Bank Stability (10):	8	8	10	8	8
Bank Vegetative Stability (10):	9	10	10	10	9
Stream Cover (10):	5	7	7	7	6
TOTAL SCORE (135):	68	119	113	114	90
HABITAT RATING:	FAIR (MODERATELY IMPAIRED)	EXCELLENT (NON-IMPAIRED)	EXCELLENT (NON-IMPAIRED)	EXCELLENT (NON-IMPAIRED)	GOOD (SLIGHTLY IMPAIRED)
Date:	7/17/2001	7/15/2001	7/15/2001	7/18/2001	7/18/2001
Weather:	Sunny	Cloudy	Cloudy	Sunny	Sunny
Air Temperature:	75 Deg. F.	72 Deg. F.	75 Deg. F.	72 Deg. F.	75 Deg. F.
Water Temperature:	63.7 Deg. F.	64.4 Deg. F.	66.9 Deg. F.	68.2 Deg. F.	64.4 Deg. F.
Ave. Stream Width:	8 Feet	25 Feet	6 Feet	25 Feet	15 Feet
Ave. Stream Depth:	0.7 Feet	1 Feet	0.5 Feet	0.75 Feet	0.666 Feet
Surface Velocity:	1 Ft./Sec.	1 Ft./Sec.	1 Ft./Sec.	0.75 Ft./Sec.	1.25 Ft./Sec.
Estimated Flow:	5.6 CFS	25 CFS	3 CFS	14.0625 CFS	12.4875 CFS
STORET No.:	70083	70029	70079	70085	70086
Stream Name:	Linder Creek	Silver River	Kalio Cr	Slate River	Ravine River
Road Crossing/Location:	l/s L'anse WWTP	Skanee Rd	Skanee Rd	Silver Rd	Sicotte Rd
County Code:	07	07	07	07	07
TRS:	50N33W05	51N32W24	51N32W23	51N31W15	51N31W02
Latitude (dd):	46.75857	46.80424	46.80204	46.80888	46.83797
Longitude (dd):	-88.4511	-88.31756	-88.3332	-88.2309	-88.21383
Ecoregion:	NLAF	NLAF	NLAF	NLAF	NLAF
Stream Type:	Coldwater	Coldwater	Coldwater	Coldwater	Coldwater
USGS Basin Code:	4020105	4020105	4020105	4020105	4020105

COMMENTS:

Table 3A. Qualitative macroinvertebrate sampling results for the Sturgeon River and Baraga County coastal watersheds, July 2001.

TAXA	STATION 1 Tioga Cr US 41 7/11/2001	STATION 2 Sturgeon River Dirt Rd off US-41 7/11/2001	STATION 3 Rock River US 141 7/12/2001	STATION 4 Kelsey Cr Plains Rd 7/12/2001
ANNELIDA (segmented worms)				
Hirudinea (leeches)	1			
Oligochaeta (worms)	1	1	1	2
ARTHROPODA				
Crustacea				
Decapoda (crayfish)	1			
Arachnoidea				
Hydracarina	1	1	1	
Insecta				
Ephemeroptera (mayflies)				
Baetidae	9	6	8	3
Caenidae		1		
Ephemerellidae	3	1	6	3
Heptageniidae	3	8	4	1
Leptophlebiidae	1	3	3	2
Tricorythidae	1	3		
Odonata				
Anisoptera (dragonflies)				
Aeshnidae	2		1	1
Cordulegastridae		2		5
Gomphidae	4	6	6	
Libellulidae		1		
Zygoptera (damselflies)				
Calopterygidae	5	1		3
Plecoptera (stoneflies)				
Leuctridae	2	1	2	7
Perlidae	5	4	7	1
Perlodidae		2	1	
Hemiptera (true bugs)				
Gerridae	3	3	2	2
Mesoveliidae	1	1	1	
Megaloptera				
Corydalidae (dobson flies)	2	1	1	2
Sialidae (alder flies)	2			1
Trichoptera (caddisflies)				
Brachycentridae	4	2	4	
Glossosomatidae		5	3	
Helicopsychidae			2	
Hydropsychidae	10	6	7	10
Hydroptilidae		1		
Lepidostomatidae		1		
Leptoceridae		1		
Limnephilidae	3	2	2	10
Philopotamidae	1	1	4	8
Uenoidae	1			
Coleoptera (beetles)				
Gyrinidae (adults)			1	
Haliplidae (adults)	1			
Elmidae	6	4	3	3
Diptera (flies)				
Athericidae		1	1	3
Ceratopogonidae		1	1	
Chironomidae	15	12	11	15
Simuliidae	3	1	3	5
Tipulidae		1		
MOLLUSCA				
Gastropoda (snails)				
Ancylidae (limpets)				2
Hydrobiidae				1
Physidae		1		
Planorbidae				2
Pelecypoda (bivalves)				
Sphaeriidae (clams)		1		
TOTAL INDIVIDUALS	91	87	86	92

Table 2B. Macroinvertebrate metric evaluation of the Sturgeon River and Baraga County coastal watersheds, July 2001.

METRIC	STATION 1 Value	STATION 1 Score	STATION 2 Value	STATION 2 Score	STATION 3 Value	STATION 3 Score	STATION 4 Value	STATION 4 Score
TOTAL NUMBER OF TAXA	27	0	34	1	26	0	23	1
NUMBER OF MAYFLY TAXA	5	1	6	1	4	0	4	1
NUMBER OF CADDISFLY TAXA	5	0	8	1	6	1	3	0
NUMBER OF STONEFLY TAXA	2	1	3	1	3	1	2	1
PERCENT MAYFLY COMP.	18.68	0	25.29	1	24.42	1	9.78	0
PERCENT CADDISFLY COMP.	20.88	0	21.84	0	25.58	0	30.43	1
PERCENT CONTR. DOM. TAXON	16.48	1	13.79	1	12.79	1	16.30	1
PERCENT ISOPOD, SNAIL, LEECH	1.10	1	1.15	1	0.00	1	5.43	0
PERCENT SURF. AIR BREATHERS	5.49	0	4.60	1	4.65	1	2.17	1
TOTAL SCORE		4		8		6		6
MACROINV. COMMUNITY RATING	ACCEPT.		EXCELLENT		EXCELLENT		EXCELLEN	

Table 3A. Qualitative macroinvertebrate sampling results for the Sturgeon River and Baraga County coastal watersheds, July 2001.

TAXA	STATION 5 Perch River US 28 7/12/2001	STATION 6 Sidnaw Cr Pequot Lake Rd 7/12/2001	STATION 7 Sturgeon River Forest Hwy 7/14/2001	STATION 8 Silver M 38 7/13/2001
ANNELIDA (segmented worms)				
Oligochaeta (worms)	2	1	1	1
ARTHROPODA				
Crustacea				
Amphipoda (scuds)		1		
Decapoda (crayfish)	1		3	
Arachnoidea				
Hydracarina		2		
Insecta				
Ephemeroptera (mayflies)				
Baetidae	7	7	4	4
Caenidae		1	6	
Ephemerellidae	3	2	1	
Heptageniidae	4	4		2
Leptophlebiidae	3	2		
Odonata				
Anisoptera (dragonflies)				
Aeshnidae	4	3	1	2
Cordulegastridae	4		1	2
Gomphidae	4	5	3	2
Libellulidae		2	4	
Zygoptera (damselflies)				
Calopterygidae	5	2	1	1
Plecoptera (stoneflies)				
Leuctridae	3	2		
Perlidae	6	1		
Pteronarcyidae		2	3	5
Hemiptera (true bugs)				
Corixidae			4	
Gerridae	2	2	1	1
Mesoveliidae	1	1		
Saldidae		1		
Megaloptera				
Corydalidae (dobson flies)	3	2		1
Sialidae (alder flies)				1
Trichoptera (caddisflies)				
Brachycentridae	2	4	3	10
Glossosomatidae	2	3		
Helicopsychidae	2			
Hydropsychidae	5	8		5
Hydroptilidae		1		
Lepidostomatidae	2			
Leptoceridae			10	
Limnephilidae	3	5	1	5
Philopotamidae	4	3	1	
Coleoptera (beetles)				
Dytiscidae (total)		2	1	
Gyrinidae (adults)			2	
Haliplidae (adults)		3		
Hydrophilidae (total)				2
Elmidae	3	1	2	
Diptera (flies)				
Athericidae	2	2		1
Ceratopogonidae	1	2	1	1
Chironomidae	15	12	18	20
Simuliidae	2	8	1	5
Tabanidae		1	1	3
Tipulidae	2	2		1
MOLLUSCA				
Gastropoda (snails)				
Ancylidae (limpets)		1		
Physidae	1	8	4	6
Pelecypoda (bivalves)				
Sphaeriidae (clams)			1	
TOTAL INDIVIDUALS	98	109	79	81

Table 3B. Macroinvertebrate metric evaluation of the Sturgeon River and Baraga County coastal watersheds, July 2001.

METRIC	STATION 5 Value	STATION 5 Score	STATION 6 Value	STATION 6 Score	STATION 7 Value	STATION 7 Score	STATION 8 Value	STATION 8 Score
TOTAL NUMBER OF TAXA	29	0	36	1	26	0	22	0
NUMBER OF MAYFLY TAXA	4	0	5	1	3	0	2	-1
NUMBER OF CADDISFLY TAXA	7	1	6	1	4	0	3	0
NUMBER OF STONEFLY TAXA	2	1	3	1	1	0	1	0
PERCENT MAYFLY COMP.	17.35	0	14.68	0	13.92	0	7.41	0
PERCENT CADDISFLY COMP.	20.41	0	22.02	0	18.99	0	24.69	0
PERCENT CONTR. DOM. TAXON	15.31	1	11.01	1	22.78	0	24.69	0
PERCENT ISOPOD, SNAIL, LEECH	1.02	1	8.26	0	5.06	0	7.41	0
PERCENT SURF. AIR BREATHERS	3.06	1	8.26	0	10.13	0	3.70	1
TOTAL SCORE		5		5		0		0
MACROINV. COMMUNITY RATING		EXCELLENT		EXCELLENT		ACCEPT.		ACCEPT.

Table 3A. Qualitative macroinvertebrate sampling results for the Sturgeon River and Baraga County coastal watersheds, July 2001.

TAXA	STATION 9 W B Sturgeon Hazel 7/13/2001	STATION 10 W B Sturgeon Pine River Rd 7/14/2001	STATION 11 Little Carp River Bear Town Rd 7/17/2001	STATION 12 Kelsey Cr US 42 7/13/2001
PLATYHELMINTHES (flatworms)				
Turbellaria		1	1	
ANNELIDA (segmented worms)				
Hirudinea (leeches)	1		1	
Oligochaeta (worms)	1	1	1	1
ARTHROPODA				
Crustacea				
Amphipoda (scuds)			1	1
Decapoda (crayfish)		1		
Arachnoidea				
Hydracarina	1			1
Insecta				
Ephemeroptera (mayflies)				
Baetiscidae		1		
Baetidae	3	3	2	5
Caenidae	3	2		1
Ephemerellidae	2			2
Ephemeridae	1			
Heptageniidae	4	5	4	
Leptophlebiidae	2			5
Odonata				
Anisoptera (dragonflies)				
Aeshnidae	1		2	2
Cordulegastridae	1	1	2	3
Gomphidae	1	4		
Libellulidae				1
Zygoptera (damselflies)				
Calopterygidae		1	1	1
Plecoptera (stoneflies)				
Leuctridae	1		2	4
Perlidae		2		1
Pteronarcyidae	3	3		
Hemiptera (true bugs)				
Corixidae		2		
Gerridae	2	1	3	2
Mesoveliidae			1	1
Saldidae	1	1	2	1
Megaloptera				
Sialidae (alder flies)			1	2
Trichoptera (caddisflies)				
Brachycentridae	3	5		
Glossosomatidae	3		1	1
Hydropsychidae	5	4	5	7
Leptoceridae		3		
Limnephilidae	4	4	9	4
Molannidae	1			
Philopotamidae			6	2
Coleoptera (beetles)				
Dytiscidae (total)	1	1		
Gyrinidae (adults)	1	1	1	
Hydrophilidae (total)	2	2	1	1
Dryopidae			1	
Elmidae	3	2	1	2
Gyrinidae (larvae)		1		
Diptera (flies)				
Athericidae	2	2	2	1
Ceratopogonidae	1	2	1	1
Chironomidae	10	15	15	18
Culicidae	1			
Dixidae			1	
Simuliidae	5	5	1	9
Tabanidae		1		
Tipulidae	1	1	4	1
MOLLUSCA				
Gastropoda (snails)				
Ancylidae (limpets)				
Physidae	4	1	1	4
Planorbidae				1
TOTAL INDIVIDUALS	75	79	74	86

Table 3B. Macroinvertebrate metric evaluation of the Sturgeon River and Baraga County coastal watersheds, July 2001.

METRIC	STATION 9		STATION 10		STATION 11		STATION 12	
	Value	Score	Value	Score	Value	Score	Value	Score
TOTAL NUMBER OF TAXA	32	1	30	1	29	1	30	1
NUMBER OF MAYFLY TAXA	6	1	4	0	2	0	4	1
NUMBER OF CADDISFLY TAXA	5	0	4	0	4	0	4	0
NUMBER OF STONEFLY TAXA	2	1	2	1	1	0	2	1
PERCENT MAYFLY COMP.	20.00	0	13.92	0	8.11	0	15.12	0
PERCENT CADDISFLY COMP.	21.33	0	20.25	0	28.38	0	16.28	0
PERCENT CONTR. DOM. TAXON	13.33	1	18.99	0	20.27	0	20.93	0
PERCENT ISOPOD, SNAIL, LEECH	6.67	0	1.27	1	2.70	1	5.81	0
PERCENT SURF. AIR BREATHERS	10.67	0	10.13	0	10.81	0	5.81	0
TOTAL SCORE		4		3		2		3
MACROINV. COMMUNITY RATING		ACCEPT.		ACCEPT.		ACCEPT.		ACCEPT.

Table 3A. Qualitative macroinvertebrate sampling results for the Sturgeon River and Baraga County coastal watersheds, July 2001.

TAXA	STATION 13 Menge Cr Menge Cr Rd 7/16/2001	STATION 14 Falls River Mead Rd 7/15/2001	STATION 15 Linden Creek u/s L'Anse WWTP 7/17/2001	STATION 16 Linden Creek d/s L'Anse WWTP 7/17/2001
PLATYHELMINTHES (flatworms)				
Turbellaria	1			
ANNELIDA (segmented worms)				
Hirudinea (leeches)	1		1	1
Oligochaeta (worms)	1	1	2	4
ARTHROPODA				
Crustacea				
Amphipoda (scuds)	12	2	5	10
Isopoda (sowbugs)	4	2		1
Arachnoidea				
Hydracarina	1	1	1	
Insecta				
Ephemeroptera (mayflies)				
Baetidae	6	6	8	
Caenidae		1		
Ephemerellidae		2	2	
Heptageniidae	2	3	2	
Leptophlebiidae			1	1
Tricorythidae		6	1	
Odonata				
Anisoptera (dragonflies)				
Aeshnidae		2	1	
Cordulegastridae		1	1	
Gomphidae		3		
Zygoptera (damselflies)				
Calopterygidae		1		
Plecoptera (stoneflies)				
Leuctridae		1		
Nemouridae	3			
Perlodidae	2	1	1	1
Pteronarcyidae		2		
Hemiptera (true bugs)				
Corixidae	1		1	1
Gerridae	1	1	1	1
Saldidae	1			
Megaloptera				
Corydalidae (dobson flies)		1		
Sialidae (alder flies)	1			
Trichoptera (caddisflies)				
Brachycentridae	5	3		
Glossosomatidae	3	2	2	
Hydropsychidae	4	3	2	
Lepidostomatidae		1		
Limnephilidae	10	8	5	2
Philopotamidae	7		2	
Coleoptera (beetles)				
Dytiscidae (total)				1
Haliplidae (adults)	1			
Hydrophilidae (total)			1	1
Elmidae	2	1	3	
Diptera (flies)				
Athericidae	1	1	2	1
Ceratopogonidae		1		35
Chironomidae	15	10	20	15
Dixidae			4	
Simuliidae	8	5	15	20
Tabanidae	1		1	
Tipulidae		3	1	
MOLLUSCA				
Gastropoda (snails)				
Ancylidae (limpets)				
Hydrobiidae				1
Physidae	2	5	2	4
Planorbidae	1	1	1	
Viviparidae				1
TOTAL INDIVIDUALS	97	81	89	101

Table 3B. Macroinvertebrate metric evaluation of the Sturgeon River and Baraga County coastal watersheds, July 2001.

METRIC	STATION 13 Value	STATION 13 Score	STATION 14 Value	STATION 14 Score	STATION 15 Value	STATION 15 Score	STATION 16 Value	STATION 16 Score
TOTAL NUMBER OF TAXA	27	1	31	1	28	1	18	0
NUMBER OF MAYFLY TAXA	2	0	5	1	5	1	1	-1
NUMBER OF CADDISFLY TAXA	5	0	5	0	4	0	1	-1
NUMBER OF STONEFLY TAXA	2	1	3	1	1	0	1	0
PERCENT MAYFLY COMP.	8.25	0	22.22	1	15.73	0	0.99	-1
PERCENT CADDISFLY COMP.	29.90	1	20.99	0	12.36	0	1.98	0
PERCENT CONTR. DOM. TAXON	15.46	1	12.35	1	22.47	0	34.65	-1
PERCENT ISOPOD, SNAIL, LEECH	8.25	0	9.88	0	4.49	0	7.92	0
PERCENT SURF. AIR BREATHERS	4.12	1	1.23	1	3.37	1	3.96	1
TOTAL SCORE		5		6		3		-3
MACROINV. COMMUNITY RATING	EXCELLENT		EXCELLENT		ACCEPT.		ACCEPT.	

Table 3A. Qualitative macroinvertebrate sampling results for the Sturgeon River and Baraga County coastal watersheds, July 2001.

TAXA	STATION 17 Silver River Skanee Rd 7/15/2001	STATION 18 Kalio Cr Skanee Rd 7/15/2001	STATION 19 Slate River Silver Rd 7/18/2001	STATION 20 Ravine River Sicotte Rd 7/18/2001
ANNELIDA (segmented worms)				
Hirudinea (leeches)	1			
Oligochaeta (worms)	1	1	2	5
ARTHROPODA				
Crustacea				
Decapoda (crayfish)		1		1
Isopoda (sowbugs)		1		
Arachnoidea				
Hydracarina		1	1	1
Insecta				
Ephemeroptera (mayflies)				
Baetidae	5	6	3	7
Ephemerellidae			2	
Ephemeridae			1	
Heptageniidae	6	5	5	4
Leptophlebiidae	2	2	2	
Tricorythidae			2	1
Odonata				
Anisoptera (dragonflies)				
Aeshnidae	2	2		2
Cordulegastridae		3	2	1
Gomphidae	2		1	3
Zygoptera (damselflies)				
Calopterygidae	3	1	1	1
Plecoptera (stoneflies)				
Leuctridae	2	3	2	5
Perlidae	3		5	2
Hemiptera (true bugs)				
Gerridae	1	2	2	1
Saldidae	1			2
Megaloptera				
Corydalidae (dobson flies)	1	2	2	3
Trichoptera (caddisflies)				
Brachycentridae	2			
Glossosomatidae	2	2	2	
Helicopsychidae	6			
Hydropsychidae	9	2	4	4
Limnephilidae	4	2	3	1
Philopotamidae	4	5	5	1
Polycentropodidae	2			
Coleoptera (beetles)				
Gyrinidae (adults)		1	1	
Hydrophilidae (total)	1		1	1
Dryopidae				2
Elmidae	1	1		1
Diptera (flies)				
Athericidae	1	2	1	3
Ceratopogonidae	1	1		
Chironomidae	18	15	15	15
Culicidae	1		1	1
Dixidae		2		
Simuliidae	6	10	3	2
Tabanidae	2			
Tipulidae	2	1	1	1
MOLLUSCA				
Gastropoda (snails)				
Ancylidae (limpets)		1	1	
Hydrobiidae			1	
Physidae	3	3	2	1
Planorbidae		1	1	
Pelecypoda (bivalves)				
Sphaeriidae (clams)			1	
TOTAL INDIVIDUALS	95	79	76	72

Table 3B. Macroinvertebrate metric evaluation of the Sturgeon River and Baraga County coastal watersheds, July 2001.

METRIC	STATION 17 Value	STATION 17 Score	STATION 18 Value	STATION 18 Score	STATION 19 Value	STATION 19 Score	STATION 20 Value	STATION 20 Score
TOTAL NUMBER OF TAXA	30	1	28	1	31	1	27	0
NUMBER OF MAYFLY TAXA	3	0	3	1	6	1	3	0
NUMBER OF CADDISFLY TAXA	7	1	4	0	4	0	3	0
NUMBER OF STONEFLY TAXA	2	1	1	1	2	1	2	1
PERCENT MAYFLY COMP.	13.68	0	16.46	0	19.74	0	16.67	0
PERCENT CADDISFLY COMP.	30.53	1	13.92	0	18.42	0	8.33	0
PERCENT CONTR. DOM. TAXON	18.95	0	18.99	0	19.74	0	20.83	0
PERCENT ISOPOD, SNAIL, LEECH	4.21	0	7.59	0	6.58	0	1.39	1
PERCENT SURF. AIR BREATHERS	4.21	1	3.80	1	6.58	0	6.94	0
TOTAL SCORE		5		4		3		2
MACROINV. COMMUNITY RATING	EXCELLENT		ACCEPT.		ACCEPT.		ACCEPT.	

Table 4. Qualitative fish sampling results for Linden Creek, July 2001.

TAXA	STATION 1 Linden Creek u/s L'Anse WWTP 7/17/2001	STATION 2 Linden Creek d/s L'Anse WWTP 7/17/2001
Salmonidae (trouts)		
Oncorhynchus mykiss (Rainbow tr.)	70	22
Salmo trutta (Brown trout)		9
Salvelinus fontinalis (Brook trout)		1
Cottidae (sculpins)		
Cottus bairdii (Mottled sculpin)	20	12
TOTAL INDIVIDUALS	90	44
Number of hybrid sunfish	0	0
Number of anomalies	0	0
Percent anomalies	0.000	0.000
Percent salmonids	77.778	72.727
Reach sampled (ft)	150	225
Area sampled (sq ft)	1,650	1,800
Density (# fish/sq ft)	0.055	0.024
Gear	bps	bps

Table 1B. Fish metric evaluation of

METRIC	STATION 1 Value	STATION 1 Score	STATION 2 Value	STATION 2 Score
TOTAL NUMBER OF TAXA	2		4	
NO. OF DARTER, SCULPIN, MADTOM TAX	1		1	
NUMBER OF SUNFISH TAXA	0		0	
NUMBER OF SUCKER TAXA	0		0	
NUMBER OF INTOLERANT TAXA	2		4	
PERCENT TOLERANT	0.00		0.00	
PERCENT OMNIVOROUS TAXA	0.00		0.00	
PERCENT INSECTIVOROUS TAXA	22.22		27.27	
PERCENT PISCIVOROUS TAXA	0.00		0.00	
% SIMPLE LITHOPHILIC SPAWNER TAXA	0.00		0.00	
TOTAL SCORE				
FISH COMMUNITY RATING		Not scored		POOR

Table 5.A Water chemistry data for the Sturgeon River and Baraga County coastal watersheds.

STATION NUMBER:		2	7	8	9	23	11	13	22
Test	Units	Sturgeon River Dirt Road	Sturgeon River Forest Rd.	Silver River M38	WB Sturgeon River Hazel Road	Little Carp River Bear Town Road	Little Carp River US41	Six Mile Creek US41	Six Mile Creek Plains Rd.
Ammonia	mg N/L	0.014	T 0.005	T 0.008	T 0.008	0.33	0.024	0.01	T .006
Boron	ug/L	K 20	K 20	31	35	K 20	K 20	K 20	K 20
Calcium	mg/L	9.7	21.5	30.5	32.2	16.7	25.5	25.3	20.9
Hardness-Calculated	mg/L	35	73	115	120	60	94	89	73
Iron	ug/L	560	160	250	78	1100	940	230	140
Magnesium	mg/L	2.6	5	9.5	9.5	4.5	7.3	6.2	5
Nitrate + Nitrite	mg N/L	0.022	0.013	T 0.003	0.082	0.031	0.011	0.013	0.054
Nitrogen - Kjeldahl	mg N/L	0.57	0.15	0.11	0.1	0.85	0.36	0.09	0.1
Phosphorus	mg P/L	0.026	0.026	0.02	0.011	0.037	0.025	0.018	0.031
Potassium	mg/L	0.4	0.9	1.5	1.2	1.1	1.6	0.6	0.4
Sodium	mg/L	2.3	2.4	2.6	3.5	3.5	2.2	2.2	K 1.0
TOC	mg/L	13	4.6	3.9	2.5	20	9	2.5	1.3
Aluminum	ug/L	K 50	K 50	114	K 50	160	148	K 50	101
Arsenic	ug/L	K 1.0	K 1.0	K 1.0	K 1.0	K 1.0	K 1.0	1.5	K 1.0
Barium	ug/L	5.2	39	53	40	33	46	52	29
Copper	ug/L	1.9	1.8	1.4	3	2.5	1.3	1.3	1.5
Lead	ug/L	K 1.0	K 1.0	K 1.0	1.2	K 1.0	K 1.0	K 1.0	K 1.0
Manganese	ug/L	34	20	37	15	256	71	23	7.6
Nickel	ug/L	K 2.0	K 2.0	2.1	2.3	K 2.0	K 2.0	K 2.0	K 2.0
Strontium	ug/L	23	53	88	89	42	63	48	23
Zinc	ug/L	K 10	K 10	K 10	20	K 10	K 10	K 10	K 10

K = Actual value is know to be less than the value given.
T = Value reported is less than reporting limit.

Table 5B. Water chemistry data for the Sturgeon River and Baraga County coastal watersheds.

STATION NUMBER:		14	15	16	17	18
Test	Units	Menge Creek Menge Cr. Road	Falls River Mead Road	Linden Creek u/s WWTP	Linden Creek d/s WWTP	Silver River Skanee Road
Ammonia	mg N/L	T 0.006	0.017	0.011	1.2	0.017
Boron	ug/L	K 20	K 20	K 20	48	K 20
Calcium	mg/L	31.7	29	35.6	36.4	23.4
Hardness-Calculated	mg/L	110	79	123	124	78
Iron	ug/L	230	200	270	450	190
Magnesium	mg/L	7.4	4.9	8.3	8.1	6
Nitrate + Nitrite	mg N/L	0.018	0.013	0.043	4.3	0.011
Nitrogen - Kjeldahl	mg N/L	0.18	0.14	0.19	1.91	0.19
Phosphorus	mg P/L	0.032	0.011	0.022	0.192	0.02
Potassium	mg/L	0.9	0.9	1.2	3	0.8
Sodium	mg/L	K 1.0	2.6	2.2	14.6	1.5
TOC	mg/L	4.6	3.4	4.9	6.1	4..8
Aluminum	ug/L	K 50	K 50	K 50	84	K 50
Arsenic	ug/L	K 1.0	K 1.0	K 1.0	K 1.0	K 1.0
Barium	ug/L	34	19	66	64	19
Copper	ug/L	1.1	1.2	1.6	2.8	1.5
Lead	ug/L	K 1.0	1.2	K 1.0	K 1.0	K 1.0
Manganese	ug/L	20	28	34	48	18
Nickel	ug/L	K 2.0	K 2.0	K 2.0	4.8	K 2.0
Strontium	ug/L	39	40	57	65	40
Zinc	ug/L	K 10	20	K 10	K 10	K 10

K = Actual value is know to be less than the value given.
T = Value reported is less than reporting limit.

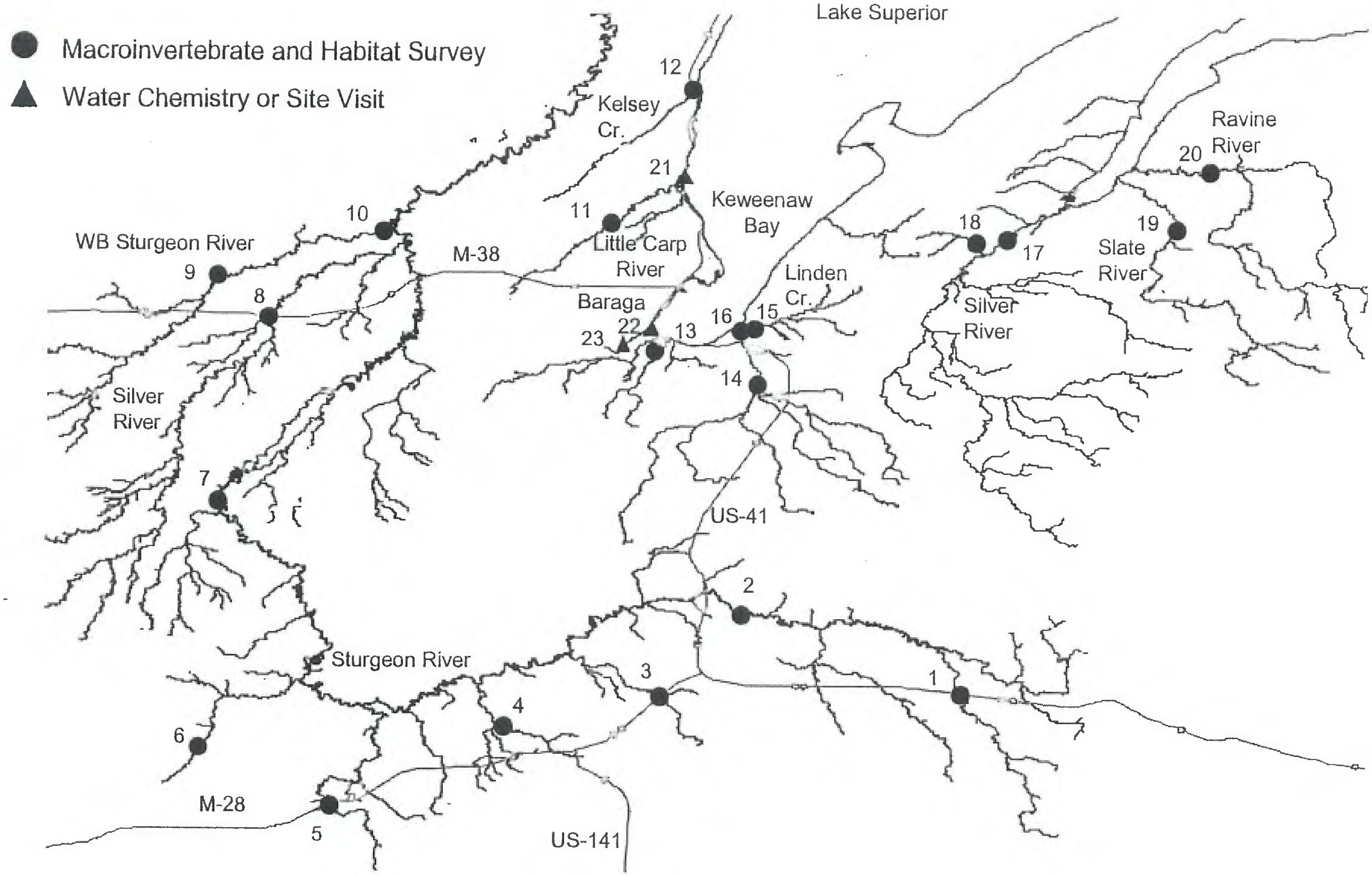
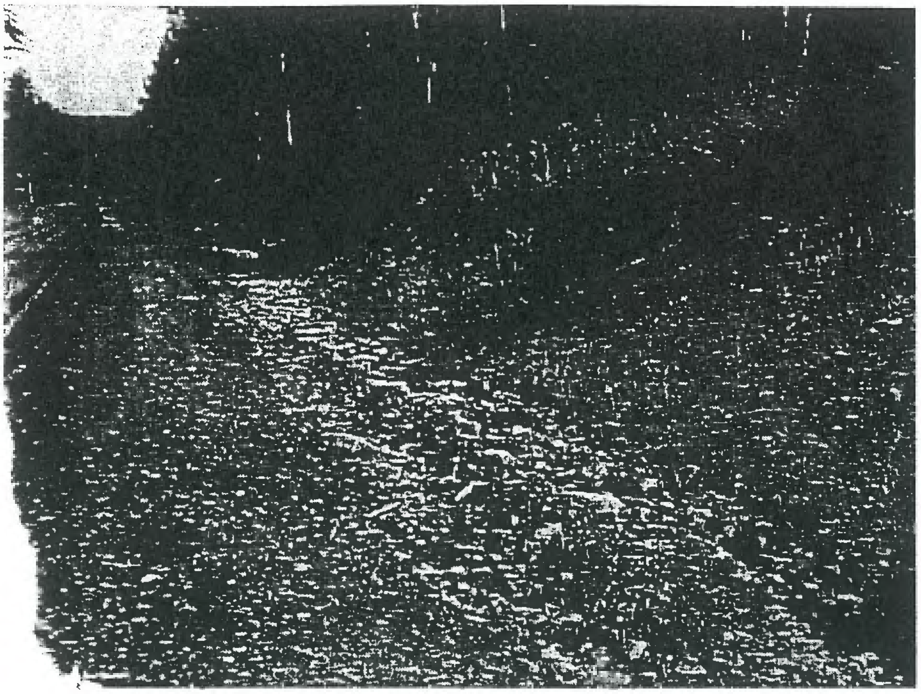


Figure 1. Biosurvey and water chemistry sampling stati... Sturgeon River watershed and Baraga County Lake Superior tributaries



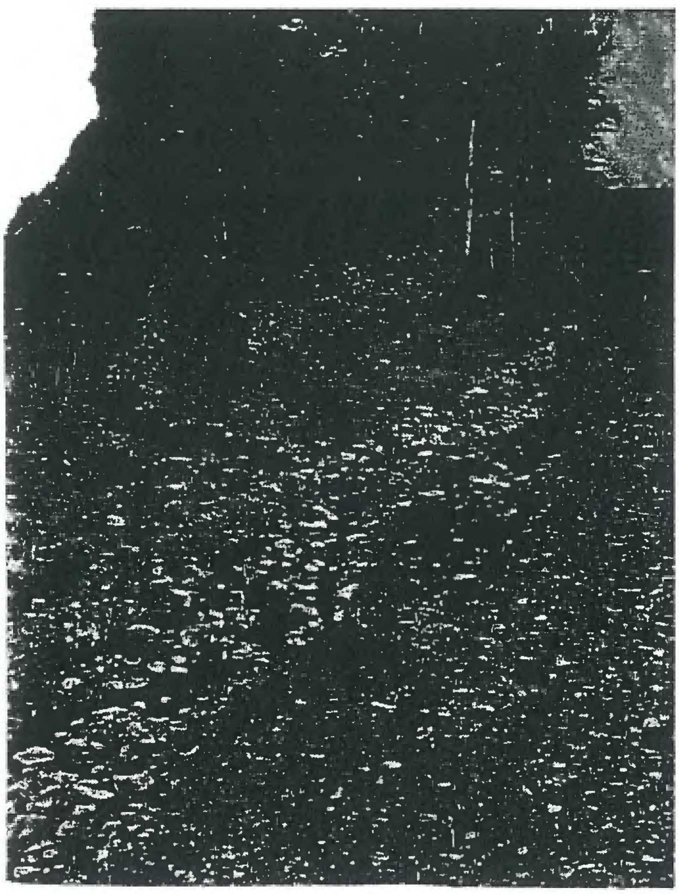


Figure 2. Road erosion along Arvon Road. Sediment from Arvon Road was observed moving across the forest floor in sheet flow and into the Slate River after a storm event.

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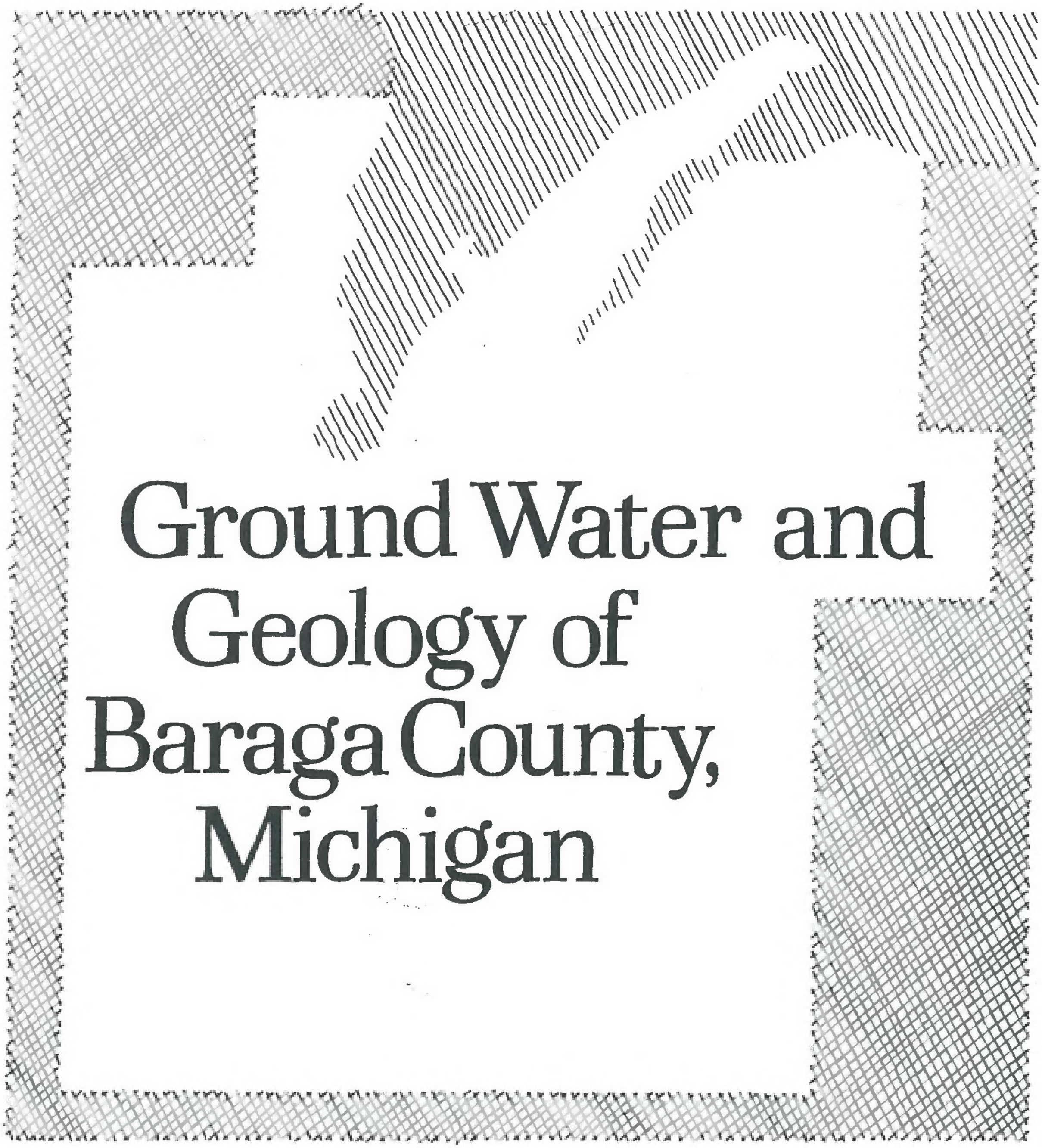

Ground Water and Geology of Baraga County, Michigan

Geological Survey Division, Department of Natural Resources

1973

The State Geological Survey collects, interprets, and disseminates basic information on the geology and mineral resources of Michigan.

Its activities are guided by public service available to all who are interested in the use or development of our resources, the protection of our environment, and sound land use management.

Geologic information is basic to these practices, and geologic reports are an important aspect of public service.

The MICHIGAN GEOLOGICAL SURVEY and the UNITED STATES GEOLOGICAL SURVEY have cooperated for many years producing basic information on water resources.

This report, one of many county, city, and area reports, is a product of that continuing program.

Geological Survey Division

Water Investigation 11

GROUND WATER AND GEOLOGY OF BARAGA COUNTY, MICHIGAN

by
C. J. Doonan, and J. R. Byerlay

Prepared in cooperation with the Water Resources Division of the Geological Survey, United States Department of the Interior

Lansing, Michigan 1973

STATE OF MICHIGAN
William G. Milliken, *Governor*

DEPARTMENT OF NATURAL RESOURCES
A. Gene Gazlay, *Director*

GEOLOGICAL SURVEY DIVISION
Arthur E. Slaughter, *State Geologist and Chief*

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PREFACE

The purpose of this report is to provide information needed in the search for water supplies from wells and springs in Baraga County.

For many years the state and federal geological surveys have cooperated in producing basic information on water resources in Michigan. This report is one product of that continuing program; and was made possible by the assistance of county agencies, municipalities, industrial concerns, well drillers, and many local residents.

Detailed records on wells and chemical analyses are included in the several tables in the Appendix at the rear of the report.

The basic information on the bedrock geology of Baraga County was furnished by Robert C. Reed of the Geological Survey Division, Department of Natural Resources. The report was reviewed by Arthur E. Slaughter of the Geological Survey Division, Department of Natural Resources. Artwork is by Jim Campbell.

Charles J. Doonan,
Engineering Technician
Water Resources Division,
Geological Survey,
United States Department of the Interior

John R. Byerlay,
Geologist and Supervisor
Water and Environment Section,
Geological Survey Division,
Michigan Department of Natural Resources

Lansing, Michigan
April 30, 1973

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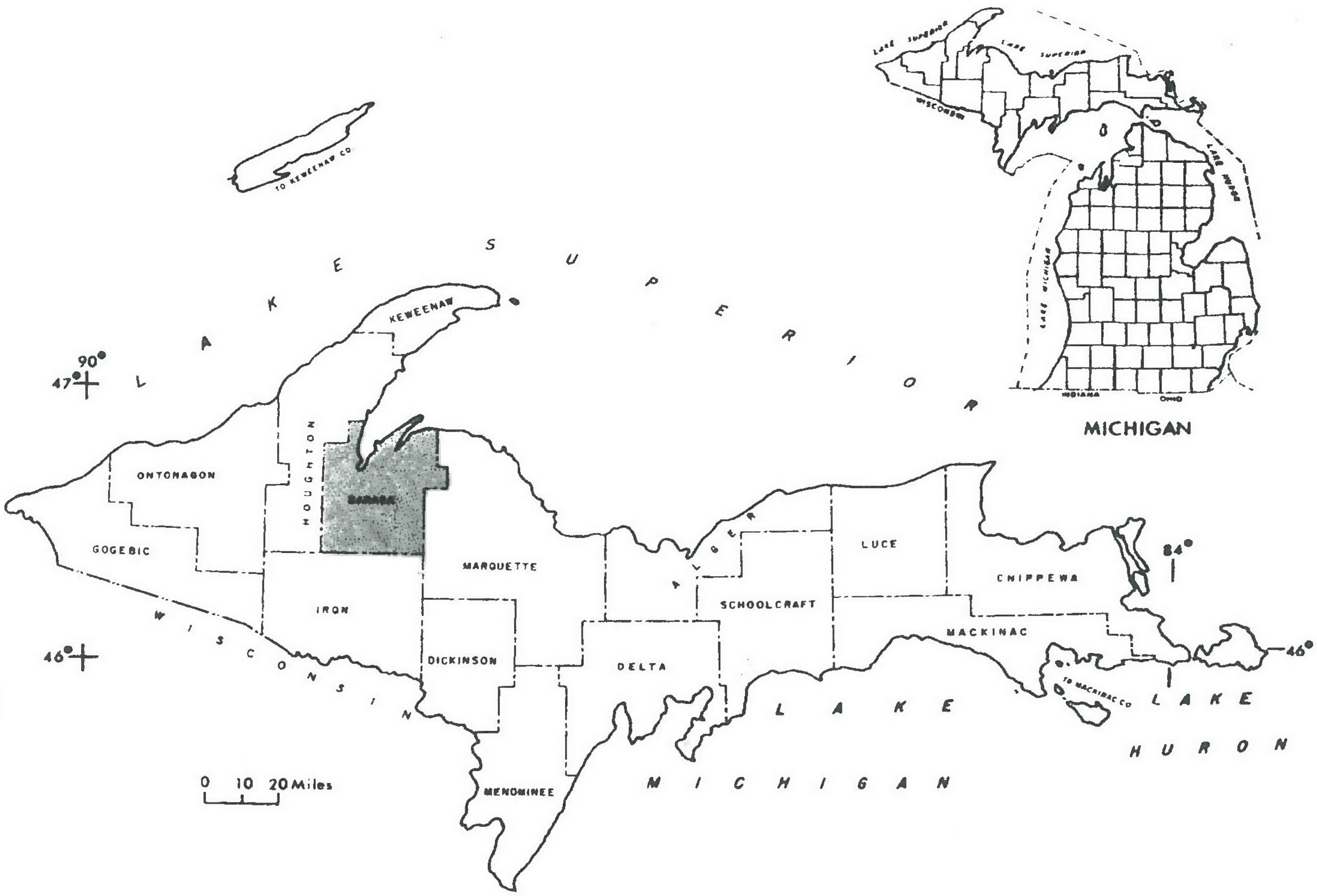

Figure 1. Location of Baraga County report area in north-western part of Michigan's Northern Peninsula.

GROUND WATER AND GEOLOGY OF BARAGA COUNTY, MICHIGAN

Abstract

Most wells in Baraga County obtain water from beds of sand and gravel in morainal and lakebed deposits or from the Jacobsville Sandstone. Yields of wells range from a few to as much as 115 gallons per minute, but most wells probably yield less than 10 gpm. Large areas, where igneous and metamorphic rocks crop out or are covered only by thin drift, are unfavorable for obtaining enough ground water for even a domestic supply. Quality of water from most wells is satisfactory, although most water supplies are hard and some are high in iron content. Some of the deeper wells in the Jacobsville Sandstone may yield salty water. Most large public water supplies are obtained from Lake Superior, but some smaller supplies are obtained from wells and springs.

INTRODUCTION

Nearly all rural residents in Baraga County depend on ground water for their domestic supplies, whereas two of the three municipal water supplies are obtained from Lake Superior. Yields of most wells are small, and in some areas it is practically impossible to obtain a supply adequate for a modern household.

This report describes the occurrence of ground water in glacial and bedrock aquifers and summarizes data on representative wells and springs. Maps showing the surface distribution of glacial materials and bedrock formations (in pocket) are keyed to the availability of ground water in the various aquifers. Included also is a map showing hydrologic data on selected wells.

Descriptions of public water supplies from all sources are included as permanent records for evaluation of future changes. Data on other wells and springs are included in the appendix.

Cooperation and Acknowledgments

For many years the State and Federal geological surveys have cooperated in making investigations of the water resources in Michigan. This report is a product of such an investigation. Assistance in obtaining data used in this report was provided by well drillers, local public officials, and village and rural residents. Bedrock geology was furnished by Robert C. Reed, Mining Geologist with the Geological Survey Division. A. E. Slaughter, State Geologist, provided encouragement and assistance in the study and reviewed the final report.

Well-Numbering System

The well-numbering system used in this report relates well location to the rectilinear system of land subdivision with reference to the Michigan prime meridian and base line. The first two parts of a well number designate the township and range; the last part designates the section and the well number within the section. Thus, "49N 33W 18-2" is the second well inventoried in section 18, Township 49 North, Range 33 West. Locations and hydrologic data of selected wells are shown on plate 1 (in pocket).

Geography

Baraga County is in the northwestern part of the Northern Peninsula of Michigan (fig. 1). The 1970 census shows a county population of 7,789, about half of which live in or near the towns of L'Anse and Baraga. Manufacturing and logging are the principal contributors to the economy. Since 1950 agriculture has rapidly declined in economic importance and at present only 6 percent of the county's 904 square miles is farmed. Beef and dairy products account for most of the farm income. Tourism, although increasing, is at present a small contributor to the economy. In 1964, tourist expenditures equaled about 4 percent of the total retail sales.

Topography and Drainage

Baraga County is generally hilly. Large rolling hills cover the northwest part of the county, except for a broad level plain along the Sturgeon River (pl. 1). A large relatively flat sandy plain lies north of the Sturgeon

River in the west-central part. North and east of U. S. 41 the hills are steep, and many large rock outcrops are present. Altitudes in this area range from 1,500 to more than 1,900 feet. Mt. Curwood (altitude 1,980 feet), the highest point in Michigan, is in this upland area. South of U.S. 41 and M-28 the hills become less steep, and broad valleys and fewer rock outcrops are present.

Altitudes range from just over 600 feet in marshy areas along Huron and Keweenaw Bays to more than 1,900 feet near the headwaters of the Peshekee River in the east-central part of the county.

Most of Baraga County is drained by the Sturgeon River (fig. 2). The Falls River and several small streams drain the north-central part and flow into Keweenaw Bay. In the northeast part, the Silver, Slate, and Ravine Rivers flow into Huron Bay. The Huron River flows into Lake Superior. The Spruce and Peshekee Rivers, which drain a small area on the east side of the county and several streams in the south tier of townships, are part of the Lake Michigan drainage basin.

GEOLOGY

The most conspicuous surface geologic feature of Baraga County is the Peshekee Upland, 1,500 to more than 1,900 feet in altitude, in the east-central part of the county (fig. 2). Precambrian bedrock is exposed or is thinly mantled with drift in the Peshekee Upland and also in large areas in the southwestern part of the county (pl. 2). Glacial drift is also thin or absent in places in the northern part, especially in areas bordering Keweenaw and Huron Bays. Areas of thicker drift occur in the Baraga Plains, Sturgeon River Valley, and the Keweenaw Moraine. Geologic maps (pl. 2) show the areal distribution of glacial deposits and bedrock.

Bedrock Formations

Lower Precambrian

Lower Precambrian rocks, chiefly composed of granite and gneiss, occur in the Peshekee Upland in the east-central part of the county (pl. 2). Topographically, this rock unit stands several hundred feet above the adjacent bedrock formations. Banded gneiss is common in this unit --- a result of engulfment and assimilation of former volcanic and sedimentary rocks by granite magmas near intrusive contacts. Older Keewatin volcanic and sedimentary rock units also occur, but are poorly represented in Baraga County as compared with Marquette County to the east. Only scattered remnants have been preserved within the layered masses of Laurentian granitic type rocks.

Middle Precambrian

Middle Precambrian rocks occur in the northeast, central, and southern parts of the county (pl. 2). The major part of the middle Precambrian rock unit is composed of Michigamme Slate and associated clastic rocks. The unit may be as thick as a few thousand feet. The Marquette Syncline, which contains iron formations, extends westward from Marquette County into the eastern part of Baraga County. Minor amounts of iron ore have been mined from the iron formations.

Upper Precambrian

The lower and middle Precambrian rock units in Baraga County are cut in places by east-west trending diabase dikes. These dikes, of late Precambrian age, though numerous, are of small areal extent and are not mapped on plate 2.

Cambrian or Precambrian Jacobsville Sandstone

The Jacobsville is a light-red to brown medium-grained quartz sandstone containing bleached spots or layers. It includes beds of fine-grained sandstone, shale, and conglomerate. The Jacobsville subcrops in the northwestern part of the county, thinning to the southeast, and pinching out at the south end of Keweenaw and Huron Bays.

The formation dips northward 1 to 5 degrees and thickens rapidly to more than 1,000 feet. Massive and crossbedded Jacobsville Sandstone is exposed in cliffs or underlies beach sand along Keweenaw and Huron Bays.

Glacial Formations

During the Pleistocene Epoch, Baraga County was traversed by vast sheets of glacial ice, which advanced and receded at least four times from the Labrador center in eastern Canada. The surficial glacial features were formed during the recession of the most recent of these glacial advances, known as the Valders advance, which terminated on the Precambrian highlands in southern Baraga County about 11,000 years ago. Baraga County was covered by the Keweenaw Lobe, a sublobe separated from the main Superior Lobe by the highlands of the Keweenaw Peninsula northwest of Baraga County. The Keweenaw Lobe moved southwestward in Keweenaw Bay, then spread generally southeastward onto the highlands.

As the Keweenaw Lobe melted back to the position of the Keweenaw Moraine in Houghton and Baraga Counties, a series of proglacial

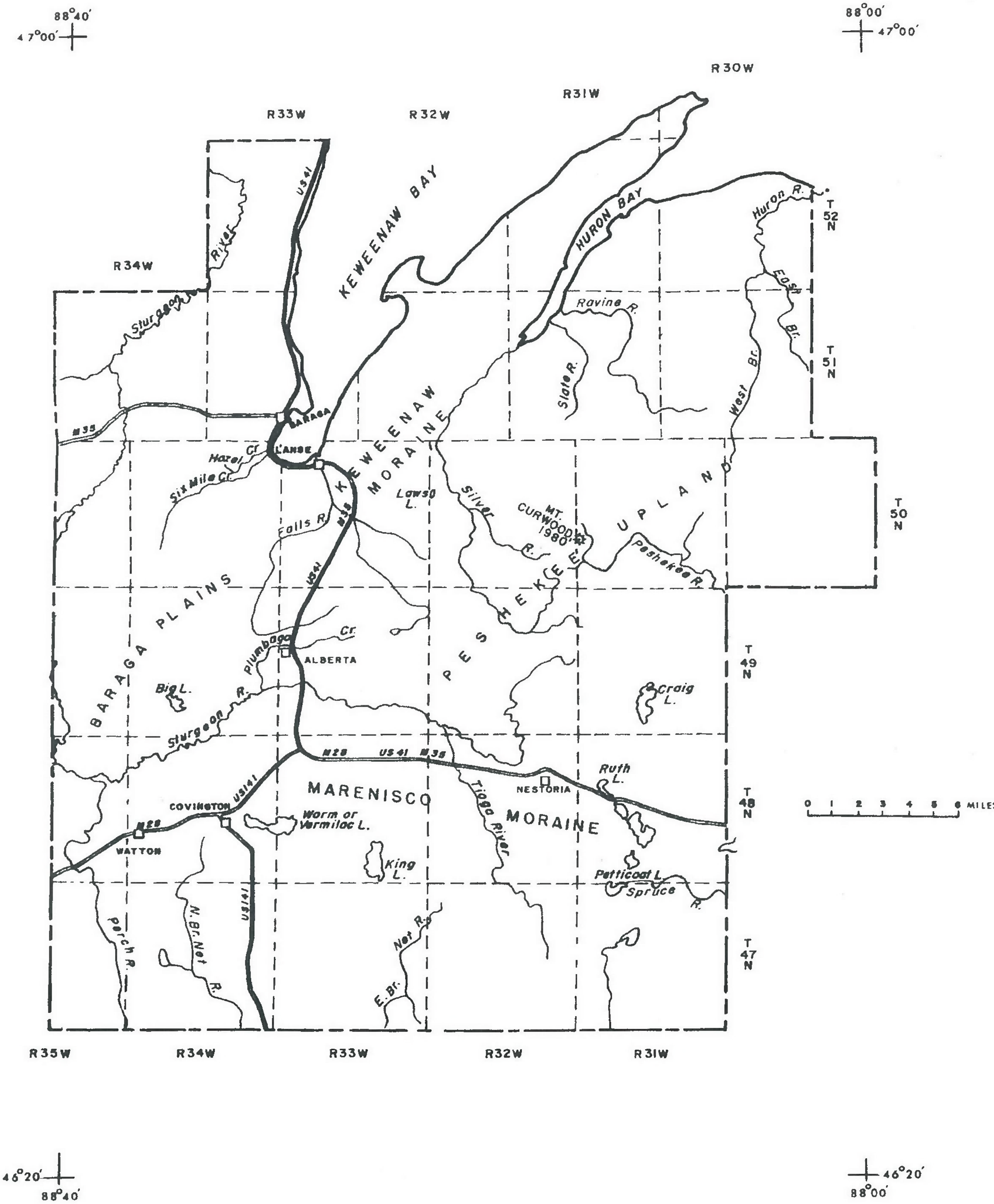

Figure 2. Principal physiographic features of Baraga County, Michigan

lakes formed from ponded melt waters. These lakes later merged into one big lake, glacial Lake Duluth, which probably occupied the western part of the Superior Basin. During the time of glacial Lake Duluth, another lake, glacial Lake Baraga, occupied the area west of Alberta known as the Baraga Plains. Hughes (1963, p. 209) implies that Lake Baraga may have existed as a small, but separate, glacial lake, at least during the early stages of Lake Duluth when the ice stood on the Keweenaw Moraine. The lake may have been connected with Lake Duluth during its later stages.

Unstratified Deposits

Unstratified glacial deposits, or glacial till, is deposited directly from the ice with little washing or sorting of material. The result is a heterogeneous mixture of clay, silt, sand, gravel, and boulders. Till was deposited as moraines during intervals when the rate of melting at the ice margin nearly equaled the rate of ice advance. Ground moraines, or till plains, were formed either by lodgement (plastering down of till at the bottom of the moving ice), or by ablation (the deposition of till by the melting and evaporation of stagnant ice). Till deposited by the Valders ice in northern Baraga County is generally pink. The coloring was caused by red hematite-rich clay from glacial Lake Keweenaw, which occupied the Superior Basin during an interglacial period before the Valders advance.

The most extensive deposits of till in Baraga County occur north and west of the Precambrian highlands. Much of the till was washed by glacial lakes, which deposited a thin layer of lake clay or sand over the till. Till also occurs in the highlands as discontinuous knolls, ridges, and as thin coverings on slopes and valley walls. The dominant surface features in the highland area, however, consist of rock knobs and swamps. Several small drumlins or drumlinoid features, possibly rock-cored, were identified by Leverett (1929) in the south-central part of the county. Leverett noted that the drumlins and drift ridges are oriented south-southwestward, parallel to the general direction of ice movement.

Moraine and ground moraines: Three major moraines were identified in Baraga County by Leverett (1929). The Keweenaw Moraine (fig. 2), which was deposited as a part of the terminal margin of the Keweenaw Bay Lobe and roughly follows the outline of Keweenaw Bay, is the best developed. The southeast edge of this moraine is banked against a steep slope of the Peshekee Upland. Much of the northwestern part of the moraine, especially southwest of L'Anse, is water-washed. Some of the till in this area could be classified as ground moraine.

The second major moraine, mapped as the Marenisco Moraine by Leverett (1929) and Martin (1957), lies in the southern third of the county south of the Sturgeon River (fig. 2). Except for somewhat thicker drift in the southeastern part of this area, and in the area north and west of Covington, the drift is limited to thin coverings on slopes plus isolated ridges, a few of which resemble drumlins. No attempt was made to map these isolated features on plate 2.

A third morainal area, 1 to 3 miles wide, extends northeastward from the Marenisco Moraine near Covington. The area was mapped as the Covington Moraine by Leverett (1929). The Covington Moraine is not delineated on figure 2, as its surface expression is little more than a thickening of the otherwise patchy veneer of drift covering parts of the highland area. Another area of thin moraine occurs northwest of the Keweenaw Moraine. The deposits here are water-washed and overlie the Jacobsville Sandstone.

Stratified Deposits

Stratified drift, in contrast to glacial till, is deposited at or near contact with the ice ablation-front or from sediment-laden glacial meltwater that eventually discharges into glacial lakes at some distance from the melting ice. This drift material is washed, sorted, and deposited in layers. The coarse materials are concentrated in areas of fast-moving water in contact with or bordering the ice, whereas the finer materials are carried outward and deposited farther from the ice, where velocities have lower energy. Two general types of stratified drift are identified, according to origin, with respect to the glacial ice. They are classified as ice-contact and proglacial stratified drift.

Ice-contact stratified drift: Ice-contact stratified drift features include eskers, kames, kame terraces, and kettles. These features result from deposition of sediment from meltwater in direct contact with the stagnant ice and are more closely associated with till than other types of stratified drift. Ice-contact drift is identified by extreme ranges in grain size, included bodies of till, and deformation in bedding due to slumping caused by melting ice.

Eskers are distinct ridges of stratified drift deposited in crevasses or tunnels at or near the base of the ice. Several eskers, as long as 4 miles, occur in the southwestern part of Baraga County.

Kames are steep-sided (generally cone-shaped) hills of ice-contact drift deposited by melt water in notches along the ice margin or in small open areas (moulins) surrounded by ice. Kettles (pits formed by delayed melting of drift-buried ice blocks) are often associated with kames, forming the characteristic "kame and kettle" topography found in many morainic areas. Kames and kettles occur in some areas of the Keweenaw and Covington Moraines in west-central Baraga County. Also, kame terraces, narrow flat-topped accumulations of stratified drift laid down by streams between a glacier and a valley wall, probably occur along the borders of some of the linear swamp-filled depressions in southwest Baraga County.

Proglacial stratified drift: Proglacial stratified drift includes outwash, stream, and lake sediments deposited by meltwater beyond the ice margin.

Outwash is deposited as broad plains along the border of a moraine. Valley-train outwash is deposited in valleys in front of the ice. Valley-train outwash grades upstream into ice-contact deposits.

The largest area of outwash in Baraga County is at the outer margin of the Keweenaw Moraine bordering the north side of the Baraga Plains. Some of this outwash is partly covered by lake sand and thin clay or silt deposited in glacial Lake Baraga. Small areas of outwash occur in stream valleys and bedrock depressions in other parts of the county, but the outwash in most of these areas is overlain by swamp deposits and Holocene alluvium.

Lake plain and stream deposits consist of stratified layers of sand, silt, and clay deposited by proglacial melt water in the form of lake beds, beaches, stream benches, bars, and deltas. Areas of thin lake clay or sand deposited during higher glacial lake levels overlie till in most of the areas of moraine and ground moraine in the northern part of the county. These areas were differentiated on the basis of soil data. In this report, they were mapped as water-washed or water-laid moraine and ground moraine, because most of the till in these features shows surface evidence of water washing.

The largest area of lake plain sediments, deposited in glacial Lake Baraga, is in west-central Baraga County. These sediments are probably as much as 200 feet thick, and consist mostly of stratified lake sand with seams of lake clay. This area is probably underlain by a "U" shaped valley of glacial origin. Large areas of sand and clay stream benches or terraces of the Sturgeon River occur in the northwestern part of the county. Smaller areas of sandy lake beds and stream benches are limited mostly to the northern part. Some beach deposits, formed during high levels of glacial Lake Nipissing, are found along Keweenaw and Huron Bays.

Areas underlain by more than 4 feet of muck and peat are mapped as swamp in this report. Stratified stream sand, gravel, and contiguous areas of muck and peat of Holocene origin are mapped as Holocene alluvium. Alluvium occurs in practically all stream valleys, but the most extensive deposits are in the Sturgeon River valley in northwestern Baraga County.

Large areas of swamp occupy depressions and stream valleys between areas of near-surface or exposed bedrock in the southern part of the county. Generally, these areas are associated with areas of Holocene alluvium too small to map, and probably contain some outwash at depth. Several small areas of manmade land, consisting of stamp sand (mill tailings) and waste rock, occur along the southern and western shores of Keweenaw Bay.

GROUND-WATER RESOURCES

Availability

Although most wells in the county yield only small supplies of water, ground water is an essential resource to most residents of farms and small villages. Much of the county is sparsely populated, and the occurrence of ground water is not well defined. A few springs are tapped for water supplies, but most ground-water supplies are obtained from wells. Hydrologic data of selected wells are summarized on plate 1 and table 1. Logs of wells are given in table 2.

Wells

Most ground-water supplies in Baraga County are obtained from drilled wells 4 to 7 inches in diameter and 50 to 300 feet deep (tables 1 and 2). About half the wells visited were drilled wells completed in bedrock. In the northwest part of the county many wells finished in bedrock, and a few deep wells finished in glacial drift, flow above land surface. In a few sandy areas small diameter drive points are used. In areas where the glacial drift consists of clay and silt, some households obtain water from large-diameter dug wells. Most dug wells are about 12 feet deep. A few very shallow wells yield water of such poor quality that it is not used for drinking or cooking.

Wells yielding water from bedrock are generally cased through overlying glacial drift and a few feet into rock. Drilled wells yielding water from glacial drift are cased down to the top of the water-bearing formation and screened in the production zone. Dug wells are generally more successful then drilled wells where the earth material is not very permeable. The large infiltration area and storage capacity of the dug well makes it possible to utilize a small rate of inflow of water. However, shallow dug wells may be subject to contamination from surface sources. Driven wells can be used only where earth materials are permeable enough to allow an adequate amount of water to enter the small-diameter drive point.

Springs

Most springs used as a water supply have been developed by enlarging the pool in the discharge area and installing a concrete or wooden box, or short length of culvert, to prevent collapse of the sides of the pool and keep out surface water. Most springs are about 3 feet in diameter and 3 to 4 feet deep and yield less than 3 gpm (gallons per minute) (table 3). If an electric pump is used, the culvert or box must be large enough to provide adequate water storage. There probably are many springs in the county that have not been developed because they are too far from the point of intended use.

Quality of Water

Most wells and springs in Baraga County yield water suitable for household and most other uses (tables 3, 4, and 5). Of the wells visited that are finished in glacial drift, more than half yield water that has iron concentrations of more than 0.3 mg/l (milligrams per liter), the maximum recommended concentration for drinking water according to the U. S. Public Health Service (1962). Only a few waters can be classed as very hard (more than 180 mg/l), and they rarely contained objectionable amounts of chloride (more than 250 mg/l). Less than half the wells tapping bedrock aquifers produce water containing more than 0.3 mg/l iron or more than 120 mg/l hardness. Well 52N 33W 9-1, which taps a sandstone aquifer at a depth of 496 feet, is the only well visited that yields water containing objectionable amounts of chloride. However, several bedrock wells in the northern part of the county reportedly were abandoned because of very salty water. Water from springs is apt to be soft to moderately hard but may contain objectionable amounts of iron (table 3). Most spring water tested was acidic with some samples showing pH readings as low as 5.8. The quality of the water in the various aquifers is included in the section on Sources and Potential of ground water.

During times of low flow the chemical composition of water from streams is generally similar to that of water from shallow aquifers, because most of the water in the streams is ground-water discharge. Water from all the streams sampled is soft to moderately hard (less than 120 mg/l), and low in dissolved solids, as indicated by specific conductance (table 6). Dissolved oxygen content of water from the streams sampled ranges from 9.0 to 10.2 mg/l, which is normal for this area.

Water from lakes is similar to water from streams, although it is generally a little softer and has a lower specific conductance (table 7).

Sources and Potential

The availability of water in glacial drift and bedrock aquifers is shown on the geologic maps on plate 2 (in pocket).

Glacial-drift Aquifers

About half the wells in Baraga County obtain water from the glacial drift. Most drift wells are less than 100 feet deep, but several in the northwest part are more than 200 feet deep. Reported yields of wells in glacial aquifers range from a few to as much as 115 gpm (table 8). Water from most wells in the drift is high in iron and most shallow wells yield water with low pH. None of the drift wells yield water that is too salty for drinking.

Moraines, ground moraines, and water-laid moraines: Most wells in the county that yield water from the glacial drift are in areas mapped as moraine or ground moraine. Three types of moraine are delineated on the surficial map (pl. 2), but well data are insufficient to demonstrate any differences in yields of wells in the different types. However, differences in composition suggest that the moraine mapped as 1 on plate 2 (above glacial lake level) will yield less water to wells than moraines mapped as 2 and 3. Most wells in morainal materials yield enough water for domestic supplies, and a few yield more than 30 gpm. Water is soft to very hard and may be high in iron content. Most wells yield water suitable for domestic use.

Lake-plain and stream benches: The largest reported well yield in the county was from a well in glacial lakebeds. This well, at Camp Baraga, yielded 115 gpm with 32 feet of drawdown (table 8). The areas of lakebeds in the western part of the county (pl. 2) will probably yield moderate supplies to wells, but only a few wells have been drilled in these deposits. Water may be hard and high in iron content but is otherwise of satisfactory quality.

Swamp deposits and Holocene alluvium: A large area of alluvium and swamp deposits occurs in the Sturgeon River valley in the northwestern part of the county (pl. 2), but few wells yield water from these materials. Elsewhere, alluvium and swamp deposits occur in smaller patches. A few wells yield small supplies of water from these deposits. Where Precambrian igneous and metamorphic bedrock is near the surface, these deposits may be the most practicable source of ground water. Water may be high in iron content.

Bedrock outcrops and areas of thin drift: Areas mapped as bedrock outcrop and thin drift are generally unfavorable for obtaining water from the drift. Supplies are generally inadequate, and iron content may be very high. The availability of water in the underlying bedrock aquifers is described below.

Bedrock Aquifers

About half the wells in the county yield water from bedrock. More than half of these obtain water from the Jacobsville Sandstone. Outside the area of Jacobsville subcrop (pl. 2), most wells in bedrock obtain water from fractured metamorphic rocks of middle Precambrian age, generally logged by well-drillers as "slates".

Jacobsville Sandstone: The Jacobsville Sandstone is the most productive bedrock aquifer in Baraga County and probably is the most reliable source of ground water. Few wells in the Jacobsville fail to yield enough water for domestic use, although two were reported abandoned because they yielded salty water. Most wells in the Jacobsville are 100 to 300 feet deep and penetrate 50 to 250 feet of the sandstone (table 2). Reported yields of wells in the Jacobsville range from 1.5 to 50 gpm, whereas specific capacities range from 0.01 to 2.5 gallons per minute per foot of drawdown (table 8). Water from the Jacobsville is generally satisfactory for domestic use, although most wells yield water that is moderately hard to very hard. Hardness, as calcium carbonate, ranges from 36 to 520 mg/l. Most wells yield water with hardness greater than 100 mg/l. Iron content ranges from 0.1 to 5.0 mg/l, and most wells yield water containing less than 0.3 mg/l iron.

Marquette Range Supergroup: The metamorphic rocks of the Marquette Range Supergroup yield water to a few wells near L'Anse and Covington. Water is apparently obtained from openings along fractures near the top of the bedrock. Reported yields of wells in these rocks will yield smaller amounts. Water from most wells in the Marquette Range Supergroup is moderately hard to very hard but is generally suitable for domestic use.

Laurentian granites and gneisses: Only one well for which records are available is known to obtain water from the granite and gneiss. This well, 42 feet deep, yields water for a domestic supply, but the yield is not always adequate for this use. The water has a hardness of 100 mg/l and iron content of 0.3 mg/l.

WATER DEVELOPMENT

Municipal Supplies

There are three municipal water systems in Baraga County, but only one uses ground water. A brief description of these systems is given below.

Ford Forestry Center at Alberta

Ford Forestry Center is owned and operated by Michigan Technological University. About 100 people live and work at the Center.

Water for domestic use is supplied from two large springs, which have been developed in an area of springs and seeps half a mile southeast of town. Each spring is protected by a covered concrete box 10 feet square by 8 feet deep. Water seeps up through sand and maintains a fairly constant level just below land surface. Water from both springs is stored in an 8,600-gallon tank. Altitude of the springs and storage tank is about 100 feet higher than the altitude at the townsite. Water is distributed to consumers by gravity flow at a pressure of about 35 pounds per square inch. Chlorine is added before the water enters the distribution system. The two springs are considered as one source and are assigned number 49N 33W 18-2.

Water for fire protection is obtained from an impoundment on Plumbago Creek, which also supplies water for a mill pond.

Chemical analysis of public supplies obtained from Lake Superior

	L'Anse	Baraga
Date Sampled	2/64	7/59
Dissolved solids in mg/l	54	52
Silica (SiO_2)	3	7
Iron (Fe)	0	0
Manganese (Mn)	0	--
Calcium (Ca)	16	12
Magnesium (Mg)	2.5	2.9
Sodium (Na)	1.8	--
Potassium (K)	0.4	--
Sodium and potassium (Na+K)	--	2.7
Bicarbonate (HCO_3)	58	56
Carbonate (CO_3)	0	--
Sulfate (SO_4)	2	2
Chloride (Cl)	0	1
Fluoride (F)	0	0
Nitrate (NO_3)	1.4	--
Hardness ($CaCO_3$)	45	42
pH	8.0	--
Specific conductance (micromhos at 25°C)	95	--

Analysis by Michigan Dept. of Public Health

L'Anse

The Village of L'Anse obtains its water supply from Lake Superior. A 12-inch intake pipe extends 1,000 feet into the lake. An average of 600,000 gallons of water per day is required to supply about 1,000 customers. Chlorine is added to the water.

Baraga

The Village of Baraga also obtains its water from Lake Superior. The intake pipe extends 800 feet into the lake. A 100,000-gallon elevated storage tank is located on a hill at the west edge of town. Chlorine is added to the water. About 350 customers are served by the water system.

Parks and Institutions

Baraga County has many campgrounds, roadside parks, and public access sites operated by several public agencies. Some have no water supply because they are located in areas where ground water is difficult to obtain. Where water supplies are available, they are described in the following paragraphs. Chemical analyses of water from most of these wells and springs are shown in tables 3 and 4.

The water supply for Baraga State Park is now from the Village of Baraga. Well 50N 34W 1-1, drilled in 1927, supplied water to the park for several years but the well failed to meet the increased demand as park facilities were expanded. This well has now been abandoned.

Water for Big Lake State Forest Campground is supplied by a hand pump on well 49N 34W 28-1. The well is 22 feet deep and finished in sand.

The Beaufort Lake State Forest Campground water supply is from well 48N 31W 21-1. This well has a 4-inch casing and is 97 feet deep. The well is completed in fine sand and is equipped with a hand pump. Water is of good quality except for the high iron content.

Laws Lake State Forest Campground has one well, 50N 32W 18-1, which was jetted through sand and gravel to a depth of 22 feet. This well has a 2-inch casing and a hand pump. Water is soft with a very high iron content.

Sturgeon River Campground, operated by the U. S. Forest Service, is supplied by a 5-inch drilled well (48N 35W 11-1) 66 feet deep, completed in bedrock. Pumping-test results indicate a yield of only 2 gpm from this well. The water is very hard but otherwise is of good quality. The well is equipped with a cylinder-type hand pump.

L'Anse Township operates a park about 1½ miles north of the Village of L'Anse. Three closely spaced springs have been developed by excavating the discharge area and installing covered boxes 2 feet square and about a foot deep. Water seeps up through bedrock into these boxes, then flows through pipes to a 12- by 12-foot concrete reservoir. From the reservoir, water flows by gravity to outlets in the park, which are about 50 feet lower in elevation. Total yield is about 3 gpm from the three springs, which have been considered as one source and assigned number 51N 33W 25-1.

L'Anse Township operates another park on Keweenaw Bay east of Pequaming known as Second Sand Beach Park. A hand pump on well 52N 32W 33-1 supplies enough water for park needs, but the water has very high iron content and a yellow color. Many park patrons obtain water for drinking and cooking from other sources. The well is reported to be 167 feet deep and is finished in bedrock.

Arvon Township Park is on the shore of Huron Bay about a mile southwest of the Village of Skanee. Well 52N 31W 27-2 has a hand pump and supplies an adequate amount of good quality water.

The U. S. Forest Service operates a picnic and rest area where M-28 crosses Perch River. Water is supplied by hand pump from well 48N 35W 34-1. This is a 5-inch drilled well 33 feet deep and finished in bedrock.

Tioga Roadside Park is maintained by the Michigan State Highway Department as a rest and picnic area where U. S. 41 crosses the Tioga River. Water is supplied by a hand pump on well 48N 32W 8-1. Yield from the well is small, but the water is of good quality.

The Michigan Corrections Department in cooperation with the Michigan Department of Natural Resources operates Baraga Corrections Camp in section 14 of T.49 N., R. 34 W. An average of 80 people live and work at the camp. Well 49N 34W 14-1 supplies an adequate amount (115 gpm) of good quality water to meet camp needs (tables 4 and 8). The well is 139 feet deep with a 6-inch casing and 16 feet of 10 slot screen set in medium sand (table 2).

Motels and Resorts

Most motels in the county are located within the service area of municipal water systems. About 3 miles south of L'Anse a resort complex consisting of a store, service station, 15 cabins, and the owner's residence obtains water from a 5-inch well 45 feet deep in bedrock (well 50N 33W 22-1).

Lakeside resorts generally obtain water

from drilled wells tapping bedrock aquifers. A 6-inch drilled well (well 52N 32W 34-1), 187 feet deep finished in bedrock, supplies water to six cottages and two homes at a resort on Sand Bay.

Household Supplies

In the northwestern part of the county most household wells are finished in bedrock at depths between 140 and 200 feet. A few wells are more than 300 feet deep. Some wells in drift and some wells in bedrock flow to the surface. East of Keweenaw Bay, domestic wells are about equally divided between bedrock and glacial-drift aquifers. In this area bedrock wells may yield salty water at depths greater than 200 feet. A few households obtain water from shallow dug wells or springs.

Well data are scarce in the central part of the county. Most household wells inventoried are less than 100 feet deep, and are finished in glacial drift. Most households near Herman (pl. 1) obtain water from shallow dug wells that have very low yields.

In the Watton-Covington area most domestic wells are less than 100 feet deep and are completed in glacial drift. Bedrock wells in this area may be as much as 150 feet deep, but most are less than 100 feet deep. Most older homes near Watton have large-diameter dug wells.

Drilled domestic wells near Three Lakes may be completed in either glacial drift or bedrock at depths from 50 to 125 feet. Some dug wells are only 12 feet deep.

Recreational Cottages and Camps

Most of the summer cottages along the shores of Keweenaw and Huron Bays have drilled wells completed in bedrock. On the west side of Keweenaw Bay well depths range from 100 to 200 feet, whereas along the shore of Huron Bay most wells in bedrock are less than 100 feet deep. On the peninsula north of Aura most cottage owners either have a spring as a source of water or draw their water directly from Keweenaw Bay.

There are many summer cottages in the Three Lakes area, most of which have drilled wells completed in glacial drift. Water from the drift in this area may contain 5 mg/l or more of iron. Nearly all the cottages with drilled wells have electric pumps and modern plumbing systems.

Hunting and fishing camps are scattered throughout the wilderness areas of the county where electricity is not available. Many of these camps are located where ground water is difficult to obtain. Some owners have developed springs, others have large diameter dug wells with hand pumps, and some do not have wells because the expense and difficulty of construction would not be justified by their limited use.

Farm Ponds

In 1969 the U. S. Soil Conservation Service reported 140 farm ponds in Baraga County. The size of the ponds ranges from less than an acre to several acres. Probably half the ponds are fed mainly by springs or ground-water seepage. The rest receive most of their water from surface runoff.

Most ponds were built as a source of water for pastured livestock, but some have been stocked with fish. At least five strawberry growers use pond water for irrigation and to combat late spring frosts.

Water Power

The rivers of Baraga County have not been extensively used to produce electric power. The Upper Peninsula Power Company operates a generating plant at Prickett Dam on the Sturgeon River. The storage reservoir is about 4 miles long by half a mile wide and extends about 2 miles into Houghton County.

# # #

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Appendix

Tables 1 through 8

Table 1. RECORDS OF WELLS

Explanation

Wells are identified according to their geographical township location, for example, "44N 38W 15-1 NE NW" refers to well no. 1 situated in the northeast quarter of the northwest quarter of section 15, of Township 44 North, Range 38 West.

Gd . . . . . . Glacial drift
BR . . . . . . Bedrock

D . . . . . . Domestic
S . . . . . . Stock
P . . . . . . Public supply

F . . . . . . Observation
A . . . . . . Abandoned

Depth and water level are in feet below land surface, F - flows above land surface.
Altitude, in feet above mean sea level, estimated from U.S.G.S. topographic maps.

Well Number	Location in section ¼ ¼	Owner	Driller	Date drilled	Diameter, in inches	Depth	Aquifer	Use	Water level	Date water level measured	Altitude	Depth to bedrock	Remarks
47N 32W 25-1	NW NW	F. Terry	Owner	----	36	6	Gd	D	4	1969	1760	----	Dug well, not used for drinking.
27-1	SE NW	American Can Co.	---	----	6	38	--	A	32.6	9-21-69	1760	----	Dry in 1965.
47N 34W 1-1	NW SW	G. R. Mahaffey	---	----	48	8	Gd	A	7	1969	1695	----	Abandoned hunting camp.
18-1	NE NE	P. Koski	---	----	--	--	Gd	D	--	----	1640	----	Hunting camp. Water temp. 7°C.
47N 35W 2-1	SE NW	A. Secci	Owner	----	1¼	17	Gd	D	--	----	1525	----	
48N 31W 17-1	NW SW	L. Lentz	Lentz	1966	7	70	BR	D	3	1969	1620	40	
17-2	SW NE	L. G. Ranta	Lentz	----	7	125	Gd	D	--	----	1620	----	
17-3	SW NE	J. Carter	Owner	1947	1¼	20	Gd	D	12	1947	1620	----	
21-1	NW NE	Mich. D.N.R.	Lentz	1966	4	97	Gd	P	--	----	1620	----	Beaufort Lake Campground.
33-1	SE NW	H. Dallmeyer	Lentz	1964	6	55	Gd	D	--	----	1720	----	Equipped with iron removal unit.
35-1	NW SE	Ed. Warren	Lentz	1968	7	60	BR	D	30	1968	1700	30	
35-2	NE NE	L. Lepisto	Lentz	1968	7	98	Gd	D	30	1968	1700	----	Very soft water.
35-3	SE SE	R. Pontti	---	----	48	12	Gd	D	9	1968	1685	----	Rock outcrop 300 feet north.
48N 32W 8-1	SW NW	Mich. Highway Dept.	---	----	--	--	--	P	--	----	1640	----	Tioga Creek roadside park.
12-1	SE SE	Wisc.-Mich. Power Co.	Owner	1949	1¼	10.0	Gd	O	7.96	10-1-69	1635	----	Observation well measured by Wisconsin-Michigan Power Co.
13-1	NE NE	Ed. Heikkinen	Lentz	1969	7	30	Gd	D	--	----	1640	----	
23-1	NE NE	A. Wilkinson	---	----	24	9	Gd	D	8	1969	1700	----	1¼-inch drop pipe inside clay tile.
48N 33W 6-1	NE SE	C. E. Delene	Maki	1961	6	46	Gd	D	--	----	1560	----	Several undeveloped springs nearby.
34W 17-2	NE NE	E. Mattson	---	----	--	55	Gd	A	--	----	1350	----	Pumped fine sand. High iron content.
18-1	SE SW	Wm. Kallio	---	----	6	50	BR	D	--	----	1460	18	Poor yield.
18-2	SE SW	Wm. Kallio	---	----	6	150	BR	D	--	----	1460	15	Good yield, supplements 18-1.
21-1	SW NE	C. A. Hutula Co.	Lentz	1967	7	37	Gd	P	5	1967	1540	37	Good yield, supplies service station.
21-2	NW SE	A. Visuri	Maki	1959	5	40	Gd	D	--	----	1580	----	Yellow color, high iron content.
22-1	NE SE	Watton Coop	---	1945	48	12	Gd	P,S	--	----	1600	----	Not used for drinking or cooking, supplies store and 4 dwellings.
22-2	NE SE	T. Heikkinen	Lentz	1968	6	38	BR	D	--	----	1600	----	Originally 36 ft. deep, poor yield. Good yield at 50 feet.
29-1	SW SE	M. Maki	Maki	----	6	49	Gd	D	--	----	1550	----	
31-1	SW NE	E. Kurti	---	1925	6	66	BR	D	--	----	1550	61	
32-1	SW NW	H. Jacobson	Owner	1962	1¼	63	Gd	D	20	1968	1540	----	
48N 35W 11-1	NW SW	U.S.F.S.	---	1964	5	66	BR	P	20	1964	1040	34	Sturgeon River Campground.
34-1	NE NE	U.S.F.S.	---	1964	5	33	BR	P	12	1964	1350	22	Perch River roadside park.
49N 31W 28-1	SW NE	Miller	---	----	7	19	Gd	D	10.69	9-22-69	1720	20	Leased by Mich. Dept. of Nat. Res.
49N 32W 6-2	NW SW	L. Moilanen	Lentz	1961	6	42	BR	D	--	----	1680	30	Will pump up to 50 gallons, then requires recharge.
49N 33W 18-1	NE SW	Mich. Tech. Univ.	Owner	1958	6	11	Gd	O	9.09	10-15-69	1290	----	Observation well in forest research project.
49N 34W 14-1	SE NE	Mich. Dept. of Admin.	Dunbar	1956	6	139	Gd	P	55	1956	1285	----	Baraga Corrections Camp.
28-1	NW SW	Mich. D.N.R.	Owner	----	2	22	Gd	P	--	----	1270	----	Big Lake Campground.
50N 31W 26-1	SE NW	C. Mager	---	----	1¼	--	Gd	D	--	----	1800	----	Well inside hunting camp.
50N 32W 18-1	NW NW	Mich. D.N.R.	Owner	1961	2	22	Gd	P	--	----	1170	----	Laws Lake Campground, high iron content.
50N 33W 3-1	SW SE	J. Vuk	Bishop	1953	5	90	Gd	D	--	----	840	----	Water cloudy.
5-1	SE NE	City of L'Anse	Gleason	1934	6	160	BR	P	F	9-24-69	610	78	Flowing well at edge of football field.
10-1	NE NW	J. Newland	Bishop	1954	4	120	Gd	D	12	1969	860	----	
11-1	NE NW	L. Bierlein	---	----	--	--	Gd	D	--	----	1000	----	Buried dug well, high iron content, cloudy.
11-2	NW NE	E. Taipalus	Bishop	1954	4	71	BR	D	--	----	990	----	Good yield but high iron content.
22-1	NW NW	L. LeClare	Bishop	1948	5	45	BR	P	--	----	980	----	Supplies residence, store, and 15 cottages.
28-2	SE SE	I. Jokinen	---	----	5	30	BR	A	--	----	1180	----	Pumping 2½ gpm for 10 minutes with hand pump drew water level below suction.

Well Number		Location in section ¼ ¼	Owner	Driller	Date drilled	Diameter, in inches	Depth	Aquifer	Use	Water level	Date water level measured	Altitude	Depth to bedrock	Remarks
50N 34W	1-1	NE NW	Mich. D.N.R.	Van Stratton	1927	--	305	BR	A	--	----	615	260	Insufficient yield for Baraga State Park supply.
	9-1	NE SE	R. Hill	Johnson	1962	5	200	Gd	D	--	----	800	----	
51N 31W	4-1	SW SW	C. Huot	Lentz	1968	7	72	BR	D	--	----	620	38	Well 120 feet deep on same lot abandoned because of high chloride content.
	8-1	SE SW	A. Johnson	Walitalo	1969	6	80	BR	D	12	1969	610	20	Water slightly cloudy.
51N 32W	8-1	SW NE	H. Struble	Johnson	1968	5	279	Gd	D	5	1968	620	----	
	8-2	NE SW	R. Pakkala	Johnson	1968	5	137	Gd	D	8	1968	620	----	
	9-1	NW NW	L. Miilu	Johnson	1967	5	266	Gd	D	14	1967	640	----	
	30-1	SW NW	R. Oakes	Johnson	1968	5	168	BR	D	35	1968	860	166	
51N 33W	15-1	SW SE	Sacred Heart Friary	Johnson	----	--	300	BR	P	--	----	680	----	
	28-1	SW NW	B. Miettinen	Johnson	1967	5	155	BR	D	40	1967	825	18	Iron content 2.5 mg/l.
	28-2	NW NE	D. Pitsley	Johnson	1968	5	118	BR	D	30	1968	790	10	Soft water.
	32-1	NE NW	F. Ojala	Johnson	1968	5	282	Gd	D	220	1968	910	----	
51N 34W	5-1	NW SE	J. Personen	Koykka	1968	5	140	BR	D	65	1968	780	5	
	7-1	NE SE	A. Heinonen	Johnson	1950	6	165	BR	D	--	----	830	----	High in iron content, acidic.
	9-1	SW SW	A. Rantila	Walitalo	1952	6	227	Gd	D,S	9	1952	660	----	
	10-1	NE NW	W. Moilanen	Walitalo	1948	6	185	BR	D	5	1969	650	85	
	15-1	NE NE	J. Pakalo	Owner	1930	1¼	72	Gd	D	--	----	660	----	Hard water.
	17-1	SW SW	G. Maki	Johnson	1941	5	375	BR	D,S	50	1962	780	0	A well 500 ft west and 425 ft deep abandoned because of high chloride content.
	18-1	SW NW	L. LaPonsie	----	1950	--	160	BR	D	--	----	740	----	Water has peculiar taste.
	20-1	NE NE	B. Tepsa	Johnson	1951	6	216	Gd	D,S	F	1969	680	----	Flow supplies adequate pressure for house and barn. Flowed 200 gpm in 1951.
	21-1	SW NE	W. Johnson	Walitalo	1946	5	315	BR	D,S	F	1969	660	125	
	24-1	SW SE	W. Jahfetson	----	1945	6	189	--	D,S	--	----	920	----	High iron content.
	24-2	NE NW	N. Wimpari	Former owner	----	48	15	Gd	D	--	----	940	----	Water soft, high iron content.
	27-1	NW SE	Wm. Mustonen	Walitalo	----	--	200	BR	D	--	----	780	----	Water hard, high iron content.
	36-1	NE NE	J. Seppanen	Johnson	1967	5	104	Gd	D	70	1967	880	----	
52N 30W	16-1	SE SW	O. DeRocher	Bishop	1966	6	151	BR	D	--	----	720	15	
	20-1	NE SW	H. Rehn	Former owner	1900±	72	22	Gd	D	15	1969	765	22	Hard water.
	28-1	SE SW	H. Britton	Walitalo	1966	6	220	BR	D,S	30	1966	860	60	
52N 31W	26-1	SW NW	G. Falk	Former owner	1914	--	26	Gd	D	18	1969	720	----	
	27-1	SE NW	G. Seldon	Walitalo	1950	--	145	BR	D	--	----	620	----	
	27-2	NW SW	Arvon Twp.	---	----	6	--	--	P	--	----	610	----	Arvon Township Park.
	29-1	SW SW	A. Keranen	Johnson	1955	--	225	BR	D	--	----	820	5	Test pumped at 3 gpm.
	32-1	NE SE	P. Kurtz	Johnson	1967	5	82	BR	D	14	1967	620	29	Nearby well more than 200 ft deep abandoned.
52N 32W	33-1	NE SE	L'Anse Twp.	---	----	--	167	BR	P	--	----	610	----	Second Sand Beach Park, high iron content.
	34-1	NE SW	A. Larson	Johnson	----	6	187	BR	P	4	1969	610	----	Supplies 2 dwellings and 6 cabins.
52N 33W	2-1	SW SW	O. Loistola	Johnson	1963	6	164	BR	D	--	----	650	40	
	2-2	NW NE	Mayer Clinic	Walitalo	1969	6	248	BR	P	47	1969	650	0	Sandstone at surface.
	9-1	SW NW	W. Myllyla	Walitalo	1947	4	496	BR	D,S	3	1969	620	466	Water is very hard, high chloride content.
	10-1	NW NW	S. Fak	Walitalo	1954	--	118	BR	D,S	6	1969	660	----	
	14-1	NW NW	V. Rantanen	Johnson	1968	5	210	BR	D	18	1968	620	1	
	14-2	NW NW	N. Brisson	Johnson	1968	5	210	BR	D	14	1968	620	1	
	14-3	NW NW	O. Drew	Siirtola	1968	6	229	BR	D	30	1968	620	0	Sandstone at surface.
	27-1	SW SW	R. Koski	Johnson	1967	5	124	BR	D	18	1967	710	10	
	27-2	NW NW	W. Menghin	Johnson	1967	5	93	BR	D	F	1967	645	10	
	29-1	SE SW	A. Koski	Former owner	1900±	60	19	Gd	D	16	1969	700	----	Soft water.
	29-2	SE SW	A. Koski	Johnson	1957	5	264	BR	S	13	1969	700	18	Soft water.
	34-1	SE NW	E. Froberg	Johnson	1968	5	85	BR	D	--	----	700	8	
	34-2	SW NE	L. Cossette	Johnson	1967	5	157	BR	D	60	1967	630	7	

Table 2. DRILLER'S WELL LOGS

Explanation

Thickness in feet. Depth in feet below land surface.
Altitude, in feet above mean sea level, estimated from U.S. Geological Survey topographic maps.

TOWNSHIP 48 NORTH:
RANGE 31 WEST

48N 31 W 17-1
L. Lentz
NW 1/4 SW 1/4 section 17
Altitude: 1620

	Thick-ness	Depth
Sand, rocks	40	40
Bedrock	30	70

48N 31W 21-1
Mich. Dept. of Natural Resources
NW 1/4 NE 1/4 section 21
Altitude: 1620

	Thick-ness	Depth
Fine sand	97	97

48N 31W 35-1
Ed. Warren
NW 1/4 SE 1/4 section 35
Altitude: 1700

	Thick-ness	Depth
Topsoil	2	2
Boulders, sand and gravel	28	30
Gray granite	30	60

48N 31W 35-2
L. Lepisto
NE 1/4 NE 1/4 section 35
Altitude: 1700

	Thick-ness	Depth
Clay, gravel, boulders	35	35
Gravel, sand	58	93
Gravel	5	98

TOWNSHIP 48 NORTH:
RANGE 32 WEST

48N 32W 13-1
E. Heikkinen
NE 1/4 NE 1/4 section 13
Altitude: 1640

	Thick-ness	Depth
Surface soil	4	4
Clay and gravel	13	17
Sand	8	25
Sand and gravel	5	30

TOWNSHIP 48 NORTH:
RANGE 33 WEST

48N 33W 6-1
C. E. Delene
NE 1/4 SE 1/4 section 6
Altitude: 1560

	Thick-ness	Depth
Sandy clay	46	46
Ledge at 46 ft.		

TOWNSHIP 48 NORTH:
RANGE 34 WEST

48N 34W 21-1
C. A. Hutula Co.
SW 1/4 NE 1/4 section 21
Altitude: 1540

	Thick-ness	Depth
Topsoil	2	2
Dirty soil	33	35
Clean gravel	2	37

TOWNSHIP 48 NORTH:
RANGE 35 WEST

48N 35W 11-1
U.S. Forest Service
NW 1/4 SW 1/4 section 11
Altitude: 1040

	Thick-ness	Depth
Boulders and gravel	34	34
Hardrock ledge	32	66

48N 35W 34-1
U.S. Forest Service
NE 1/4 NE 1/4 section 34
Altitude: 1350

	Thick-ness	Depth
Gravel and boulders	22	22
Hardrock ledge	11	33

TOWNSHIP 49 NORTH:
RANGE 31 WEST

49N 31W 28-1
Miller
SW 1/4 NE 1/4 section 28
Altitude: 1720

	Thick-ness	Depth
Glacial drift	20	20
Bedrock	2	22

TOWNSHIP 49 NORTH:
RANGE 34 WEST

49N 34W 14-1
State of Michigan
SE 1/4 NE 1/4 section 14
Altitude: 1285

	Thick-ness	Depth
Hard dry red sand	45	45
Soft red clay, sandy	50	95
Dirty fine sand	25	120
Clean fine sand, water	19	139
Dirty very fine sand	3	142

49N 34W 28-1
Mich. Dept. of Natural Resources
NW 1/4 SW 1/4 section 28
Altitude: 1270

	Thick-ness	Depth
Sand	22	22

TOWNSHIP 50 NORTH:
RANGE 32 WEST

50N 32W 18-1
Mich. Dept. of Natural Resources
NW 1/4 NW 1/4 section 18
Altitude: 1170

	Thick-ness	Depth
Medium sand, fine gravel	22	22

TOWNSHIP 50 NORTH:
RANGE 33 WEST

50N 33W 5-1
City of L'Anse
SE 1/4 NE 1/4 section 5
Altitude: 610

	Thick-ness	Depth
Surface fill	3	3
Clay and sand	17	20

50N 33W 5-1 (cont.)

	Thick-ness	Depth
Sand, fine; and gravel	1	21
Muck, black, and sand	9	30
Sand and clay	4	34
Gravel, fine	5	39
Sand and gravel	3	42
Clay, red	11	53
Hardpan	2	55
Clay	5	60
Gravel	13	73
Clay	5	78
Gravel	1/2	78 1/2
Slate ledge	82	160 1/2

TOWNSHIP 50 NORTH:
RANGE 34 WEST

50N 34W 1-1 (abandoned, (insufficient water)
Mich. Dept. of Natural Resources
NE 1/4 NW 1/4 section 1
Altitude: 615

	Thick-ness	Depth
Pleistocene:		
No record	260	260
Bedrock:		
Slates, greenish gray & reddish, some pink sandstone may be Lake Superior sandstone of Cambrian age	45	305

TOWNSHIP 51 NORTH:
RANGE 31 WEST

51N 31W 4-1
C. Huot
SW 1/4 SW 1/4 section 4
Altitude: 620

	Thick-ness	Depth
Topsoil	3	3
Sand	22	25
Clay	13	38
Ledge	34	72

51N 31W 8-1
A. Johnson
SE 1/4 SW 1/4 section 8
Altitude: 610

	Thick-ness	Depth
Gravel and boulders	10	10
Clay	10	20
Slate rock	60	80

TOWNSHIP 51 NORTH:
RANGE 32 WEST

51N 32W 8-1
H. Struble
SW 1/4 NE 1/4 section 8
Altitude: 620

	Thick-ness	Depth
Coarse gravel, clayey	5	5
Clay, with coarse gravel	30	35
Clay, with fine gravel	40	75
Sand, clayey	30	105
Clay, with fine gravel	60	165
Gravel, some clay	10	175
Sand, clayey, fine	50	225
Clay, hard, some gravel	20	245
Sand, fine, clayey	18	263
Sand, with some clay	7	270
Sand, coarse, water bearing	9	279

	Thickness	Depth
51N 32W 8-2		
R. Pakkala		
NE 1/4 SW 1/4 section 8		
Altitude: 620		
Sand, Clayey	14	14
Clay, with gravel	34	48
Sand, clayey	29	77
Clay, with coarse gravel	30	107
Sand, clayey	18	125
Sand, fine	8	133
Sand, coarse	4	137
51N 32W 9-1		
L. Miilu		
NW 1/4 NW 1/4 section 9		
Altitude: 640		
Sand, yellow, fine	6	6
Sand, clayey	10	16
Clay, with gravel	30	46
Clay, with fine gravel	60	106
Sand, clayey	50	156
Clay, with coarse gravel	40	196
Sand, clayey	35	231
Sand, with some clay	15	246
Sand, white, fine	10	256
Sand, coarse	10	266
51N 32W 30-1		
R. Oakes		
SW 1/4 NW 1/4 section 30		
Altitude: 860		
Sand, clayey	4	4
Clay, with some gravel	3	7
Clay, with some sandstone	2	9
Sandstone, cavey	3	12
Sandstone, firm	154	166
Slaterock	2	168
TOWNSHIP 51 NORTH: RANGE 33 WEST		
51N 33W 28-1		
B. Miettinen		
SW 1/4 NW 1/4 section 28		
Altitude: 825		
Sand, clayey	6	6
Clay, fine sand	3	9
Clay, red	3	12
Sandstone, with clay, clayey	6	18
Sandstone, firm	137	155
51N 33W 28-2		
D. Pitsley		
NW 1/4 NE 1/4 section 28		
Altitude: 790		
Sand, clayey	4	4
Clay with fine gravel	3	7
Clay with sandstone	3	10
Sandstone, firm	108	118
51N 33W 32-1		
F. Ojala		
NE 1/4 NW 1/4 section 32		
Altitude: 910		
Clay, with fine gravel	10	10
Sand, clayey	10	20
Clay, soft	20	40
Sand, clayey	20	60
Gravel, some clay	30	90
Sand, white, coarse, dry	80	170
Gravel, some clay	20	190
Sand, clayey	60	250
Sand, fine clayey	20	270
Gravel, some clay	8	278
Sand, with coarse gravel	4	282
TOWNSHIP 51 NORTH: RANGE 34 WEST		
51N 34W 5-1		
J. Pesonen		
NW 1/4 SE 1/4 section 5		
Altitude: 780		
Clay	5	5
Sandstone	135	140
51N 34W 10-1		
W. Moilanen		
NE 1/4 NW 1/4 section 10		
Altitude: 650		
Glacial drift	85	85
Sandstone	100	185
51N 34W 20-1		
B. Tepsa		
NE 1/4 NE 1/4 section 20		
Altitude: 680		
Sand	15	15
Clay	200	215
Gravel	1	216
51N 34W 36-1		
J. Seppanen		
NE 1/4 NE 1/4 section 36		
Altitude: 880		
Sand, yellow, fine	12	12
Sand, clayey	6	18
Clay, with fine gravel	15	33
Clay, soft	25	58
Sand, clayey	20	78
Sand, fine, some clay	10	88
Sand, fine	6	94
Sand, coarse, water bearing	10	104
TOWNSHIP 52 NORTH: RANGE 30 WEST		
52N 30W 16-1		
O. DeRocher		
SE 1/4 SW 1/4 section 16		
Altitude: 720		
Glacial drift	15	15
Sandstone	136	151
52N 30W 20-1		
H. Rehn		
NE 1/4 SW 1/4 section 20		
Altitude: 765		
Sandy clay	22	22
Bedrock at 22		
52N 30W 28-1		
H. Britton		
SE 1/4 SW 1/4 section 28		
Altitude: 860		
Glacial drift	60	60
Bedrock	160	220
TOWNSHIP 52 NORTH: RANGE 31 WEST		
52N 31W 29-1		
A. Keranen		
SW 1/4 SW 1/4 section 29		
Altitude: 820		
Glacial drift	5	5
Rock	220	225
52N 31W 32-1		
P. Kurtz		
NE 1/4 SE 1/4 section 32		
Altitude: 620		
Sand, clayey	4	4
Gravel, some clay	6	10
Gravel, coarse, clayey	10	20
Clay, with fine gravel	5	25
Sandstone, cavey, clayey	4	29
Sandstone, firm	53	82
TOWNSHIP 52 NORTH: RANGE 33 WEST		
52N 33W 2-2		
Mayer Clinic		
NW 1/4 NE 1/4 section 2		
Altitude: 650		
Sandstone	248	248
52N 33W 14-1		
V. Rantanen		
NW 1/4 NW 1/4 section 14		
Altitude: 620		
Clay, with gravel	1	1
Sandstone, cavey	2	3
Sandstone, firm	207	210
52N 33W 14-2		
N. Brisson		
NW 1/4 NW 1/4 section 14		
Altitude: 620		
Clay, with gravel	1	1
Sandstone, cavey	2	3
Sandstone, firm	207	210
52N 33W 14-3		
O. Drew		
NW 1/4 NW 1/4 section 14		
Altitude: 620		
Red sandstone	229	229
52N 33W 27-1		
R. Koski		
SW 1/4 SW 1/4 section 27		
Altitude: 710		
Sand, clayey	3	3
Clay, with fine gravel	5	8
Clay and stones	2	10
Sandstone	114	124
52N 33W 27-2		
W. Menghin		
NW 1/4 NW 1/4 section 27		
Altitude: 645		
Clay, sandy	8	8
Clay, red	2	10
Sandstone, cavey	3	13
Sandstone, firm	80	93
52N 33W 34-1		
E. Froberg		
SE 1/4 NW 1/4 section 34		
Altitude: 700		
Clay with fine gravel	3	3
Clay with some sandstone	5	8
Sandstone, cavey	3	11
Sandstone, firm	74	85
52N 33W 34-2		
L. Cossette		
SW 1/4 NE 1/4 section 34		
Altitude: 630		
Sand, clayey	2	2
Clay with fine gravel	2	4
Clay, hard	3	7
Sandstone, cavey	3	10
Sandstone, firm	147	157

Table 3. RECORDS OF SPRINGS

Altitude in feet above mean sea level, estimated from U. S. Geological Survey topographic maps
Chemical analysis made in field by U. S. Geological Survey personnel

D – Domestic
P – Public supply

Spring Number	Location in Section	Owner	Altitude	Use	Date sampled	Temperature (°C)	Estimated yield (gpm)	Specific conductance, Micromhos at 25°C	pH	Alkalinity	Non carbonate hardness	Dissolved solids	Bicarbonate HCO_3	Carbonate CO_3	Sulfate SO_4	Chloride CL	Nitrate NO_3	Hardness $CaCO_3$	Iron Fe	Remarks
										Dissolved constituents in milligrams per liter, except as indicated.										
47N 31W 32-1	SE-NE	B. C. Mattson	1640	D	9-21-69	8.5	10	85	5.8	32	3	55	--	0	11	0.5	0.3	35	0.50	Water seeps from area 50 ft. in diameter.
48N 34W 17-1	NE-NE	Eino Mattson	1330	D	9-19-69	8.0	2	330	7.7	--	--	217	166	0	12	10	1.7	140	.10	48" concrete tile sunk 5 ft. in ground. Electric pump supplies house.
49N 32W 6-1	SW-SW	Charles Bantes	1665	D	9-22-69	14.0	--	245	7.9	—	—	155	140	0	9.0	3.0	1.3	120	1.3	30" clay tile sunk 4 ft. in ground. Electric pump supplies house.
49N 33W 18-2	SW-SW	Michigan Technological University	1400	P	9-10-69	--	—	220	6.9	—	--	—	--	0	8.0	18	1.6	85	.50	See discussion of public supply for Ford Forestry Center at Alberta.
50N 32W 18-2	SW-NE	Celetex Corporation	1210	P	9-22-69	8.0	2	200	7.3	88	12	114	107	0	12	1.0	.3	85	2.2	3' x 3' concrete box sunk 3 ft. in ground. Concrete box at roadside. Drinking water for nearby residents obtained here.
50N 33W 28-1	SE-SE	C. Forcia	1120	D	9-20-69	8.5	2	250	6.9	—	--	159	--	0	15	15	2.7	140	.30	3' x 3' metal box sunk 2 ft. in ground. Electric pump supplies house.
51N 33W 25-1	NW-SE	L'Anse Township	720	P	8-12-69	12.0	3	115	5.9	26	10	65	32	0	4.0	8.5	.1	50	.50	See discussion of public supply at L'Anse Township Park.
52N 31W 19-1	SW-NW	Eli Ketola	695	D	8-13-69	9.5	1	110	5.9	--	--	—	—	--	—	—	--	50	.10	30" clay tile sunk 4 ft. in ground has flowed since 1945. Electric pump supplies house.
53N 31W 35-1	SW-SE	F. B. Waisanen	630	D	8-13-69	9.5	1	95	5.9	28	5	55	33	0	5.0	1.1	1.0	35	.10	

Table 4. CHEMICAL ANALYSIS OF WATER FROM WELLS

Chemical analyses made in field by U. S. Geological Survey personnel

Aquifer: BR - Bedrock
Gd - Glacial drift

Well number	Aquifer	Date	Temperature °C	Specific conductance Micromhos at 25°C	pH	Alkalinity	Non carbonate hardness	Dissolved solids	Bicarbonate HCO_3	Carbonate CO_3	Sulfate SO_4	Chloride Cl	Nitrate NO_3	Hardness $CaCO_3$	Iron Fe
						Dissolved constituents in milligrams per liter, except as indicated.									
47N 32W 25-1	Gd	9-21-69	11	50	6.8	2	10	32	3	0	15	1.5	4.3	12	1.5
47N 34W 18-1	Gd	9-19-69	7	245	6.8	--	0	130	--	0	9.0	1.0	.1	100	5.0
47N 35W 2-1	Gd	9-19-69	--	50	5.5	--	--	--	--	0	11	1.5	.6	12	.20
48N 31W 17-1	BR	8-20-69	--	160	7.9	76	0	140	93	0	7.0	1.3	.0	74	.40
17-2	Gd	8-21-69	--	145	8.2	84	0	110	102	0	5.0	.5	.1	85	.20
17-3	Gd	8-21-69	--	50	6.1	8	4	30	10	0	2.0	.7	.2	12	.10
21-1	Gd	9-21-69	8.5	200	7.4		2	117		0	8.0	4.5	.0	90	5.0
33-1	Gd	8-21-69	--	100	6.8	46	0	5	56	0	.0	1.0	.0	38	5.0
35-1	BR	9-17-69	--	150	7.5	25	24	98	30	0	17	8.5	31	50	.10
35-2	Gd	9-17-69	--	85	7.6	29	5	55	35	0	16	.5	.5	34	2.0
35-3	Gd	9-21-69	10.5	50	5.8	--	--	30	--	0	9.0	.5	.7	10	.60
48N 32W 8-1		8-20-69	8	100	7.1	37	5	65	45	0	4.0	2.2	.0	42	1.9
48N 33W 6-1	Gd	9-24-69	--	340	7.5	--	--	220	--	0	11	1.0	5.7	180	.10
48N 34W 18-1	BR	9-23-69	--	--	--	--	--	--	--	0	22	10	.8	200	.10
18-2	BR	9-23-69	--	340	7.5	173	0	221	205	5	18	.0	.1	140	.60
21-1	Gd	9-17-69	--	330	7.8	167	0	202		0	15	.0	.1	150	1.4
21-2	Gd	9-23-69	--	115	6.0	--	--	--	--	0	7.0	1.0	2.3	39	5.0
22-1	Gd	9-17-69	--	325	7.2	--	--	--	--	0	8.0	40	.3	85	5.0
22-2	BR	9-24-69	--	255	6.5	--	--	--	--	0	7.0	32	4.8	78	.30
28-1	BR	9-23-69	--	325	7.7			202		0	11	2.0	5.7	160	.30
29-1	Gd	9-23-69	--	220	8.3	105	0	130	127	1	9.0	.5	.2	86	.10
31-1	BR	9-23-69	--	265	7.9			162		1	14	1.0	.2	130	.30
32-1	Gd	9-23-69	--	235	7.4	--		--	--	0	7.0	.0	1.2		1.9
48N 35W 11-1	BR	9-19-69	8	455	7.4	--	--	273	--	0	6.0	5.0	.1	240	1.4
34-1	BR	9-17-69	9	220	8.3	92	6	133	110	2	10	5.0	1.1	98	.10
49N 31W 28-1	Gd	9-21-69	--	80	6.0		--	52	--	0	10	1.5	.2	30	5.0
49N 32W 6-2	BR	9-22-69	--	240	7.8			143		0	9.0	.8	.2	110	.30
49N 34W 14-1	Gd	9-24-69	--	170	8.2	94	0	110	115	0	6.0	.0	.7	94	.20
28-1	Gd	9-19-69	10	80	7.8	36	0	52	44	0	8.0	1.0	.2	35	.30
50N 32W 18-1	Gd	9-22-69	10	155	6.3	--	--	101	--	--	6.0	.0	.0	65	5.0
50N 33W 3-1	Gd	9-23-69	--	880	7.8	115	61	468	139	2	7.0	160	0.1	260	1.1
5-1	BR	9-24-69	8	225	8.1	106	0	143	129	0	2.0	5.0	.2	100	.10
10-1	Gd	9-24-69	--	350	8.5	177	0	214	209	6	7.0	4.0	.2	110	.10
11-1	Gd	9-23-69	--	150	6.4	--	--	97	--	0	11	.5	.1	64	5.0
11-2	BR	9-23-69	--	300	6.4	--	--	188	--	0	16	1.0	.1	140	1.2
22-1	BR	9-11-69	--	220	8.3	--	--	143	--	0	10	3.5	.1	100	.20
28-2	BR	9-20-69	8.5	270	8.4	126	10	176	154	3	16	6.5	.8	140	5.0
50N 34W 9-1	Gd	9-11-69	--	320	8.0	176	0	208	209	0	8.0	1.0	.2	170	2.5

Table 4. CHEMICAL ANALYSIS OF WATER FROM WELLS --- Continued

Chemical analyses made in field by U. S. Geological Survey personnel

Aquifer: BR - Bedrock
Gd - Glacial drift

Well number	Aquifer	Date	Temperature °C	Specific conductance Micromhos at 26°C	pH	Alkalinity	Non carbonate hardness	Dissolved solids	Bicarbonate HCO_3	Carbonate CO_3	Sulfate SO_4	Chloride Cl	Nitrate NO_3	Hardness $CaCO_3$	Iron Fe
						Dissolved constituents in milligrams per liter, except as indicated.									
51N 31W 4-1	BR	8-14-69	--	260	7.8	127	0	196	155	0	3.0	1.5	1.1	130	.20
8-1	BR	8-14-69	--	110	6.5	46	0	71	56	0	4.0	1.5	.1	46	.30
51N 32W 9-1	Gd	8-13-69	--	280	8.0	143	0	182	175	0	.0	.3	.1	130	1.1
30-1	BR	8-13-69	--	240	7.8	124	0	159	151	0	1.5	.6	.1	100	.20
51N 33W 15-1	BR	9-23-69	--	475	6.5	--	--	306	--	0	25	71	2.9	60	.20
28-1	BR	9- 9-69	--	130	6.2	--	--	84	--	0	10	4.5	.1	50	2.5
28-2	BR	9- 9-69	--	100	5.9	--	--	65	--	0	9.0	1.5	.4	50	.10
32-1	Gd	9- 9-69	--	320	7.7	--	--	200	--	0	12	18	2.7	170	.10
51N 34W 5-1	BR	9- 9-69	--	320	7.8			208		0	5.0	1.0	.7	150	.10
7-1	BR	9-10-69	--	75	5.5	--	--	--	--	0	9.0	1.0	.2	23	3.5
9-1	Gd	9- 9-69	--	285	8.3	100	0	124	121	1	11	2.5	.3	85	.10
10-1	BR	9-10-69	--	330	8.2	83	9	202	101	0	54	19	.4	92	.20
15-1	Gd	9-11-69	--	500	7.3	--	--	--	--	0	10	1.0	.3	250	.10
17-1	BR	9-10-69	--	480	7.1	--	--	--	--	0	14	16	.5	220	.30
18-1	BR	9-10-69	--	210	8.1	112	0	136	137	0	12	3.0	.4	97	.10
20-1	Gd	9-10-69	8.5	195	8.4	104	0	127	124	2	10	2.5	.5	92	.10
21-1	BR	9-11-69	--	500	8.5	161	0	325	189	6	8.0	71	.4	59	.40
24-1		9-11-69	--	115	5.5	--	--	75	--	0	11	3.5	2.4	50	1.0
24-2	Gd	9-11-69	--	55	5.4	--	--	38	--	0	14	3.5	2.1	15	1.3
27-1	BR	9-11-69	--	430	8.0		--	280		0	8.0	1.0	.2	200	1.0
36-1	Gd	9- 9-69	--	400	7.5	--	--	--	--	0	15	32	2.6	190	.10
52N 30W 16-1	BR	9-18-69	--	225	7.4	0	0	143	--	0	7.0	.5	.4	110	.10
20-1	Gd	8-14-69	--	450	7.5	181	21	325	221	0	9.0	8.5	39	200	.10
28-1	BR	8-19-69	--	230	6.0	89	3	156	108	0	5.0	6.5	17	91	.10
52N 31W 26-1	Gd	8-14-69	--	155	6.3	62	2	100	76	0	4.0	1.5	5.8	64	0.10
27-1	BR	8-14-69	--	500	7.2	140	3	325	171	0	4.0	6.3	.3	140	.10
27-2		9-18-69	7	240	7.0						11	5.5	.3	61	1.8
29-1	BR	8-12-69	--	300	7.5	155	0	198	189	0	.0	1.0	.3	130	.30
32-1	BR	8-13-69	--	240	8.0	119	0	155	145	0	2.0	.8	.7	120	.10
52N 32W 33-1	BR	8-13-69	8	260	7.9	137	0	175	167	0	.0	.3	.0	130	3.8
34-1	BR	8-12-69	--	300	7.9	156	0	202	190	0	1.0	.5	.1	130	.10
52N 33W 2-1	BR	8-27-69	--	450	8.3	87	7	280	106	0	31	68	.2	94	.10
9-1	BR	8-28-69	--	2100	7.6	31	500	1400	38	0	14	620	.0	520	.10
10-1	BR	8-27-69	--	265	7.8	138	0	169	168	0	.0	1.0	.0	130	.10
14-1	BR	8-20-69	--	400	7.7	124	0	247	151	0	12	39	.0	100	.10
27-1	BR	8-20-69	--	230	7.3	110	0	143	134	0	5.0	2.5	.2	82	.10
29-1	Gd	8-21-69	--	105	6.0	18	20	62	46	0	10	6.0	12	38	.10
29-2	BR	8-21-69	--	280	8.1	120	0	182	146	0	18	5.0	.1	36	.20
34-1	BR	8-27-69	--	300	7.7	151	0	195	184	0	5.0	3.0	.1	94	.10

Table 5. SOURCE AND SIGNIFICANCE OF PRINCIPAL CONSTITUENTS IN WATER IN BARAGA COUNTY

Parameter	Maximum recommended concentration 1/	Source	Significance
Iron *Fe*	0.3 mg/l	Iron-bearing minerals in most formations	Adds a brownish stain to porcelain, laundered goods, etc. Imparts a bitter taste.
Bicarbonate & Carbonate HCO_3 & CO_3	--	Carbon dioxide and carbonate minerals such as limestone and dolomite	Raises the alkalinity and pH of water. In combination with calcium and magnesium causes carbonate hardness and scale. Releases corrosive carbon dioxide gas on heating.
Sulfate SO_4	250 mg/l	Shales and Gypsum, oxidation of sulfides	Commonly has a laxative effect with concentrations of 600 to 1,000 mg/l, particularly when associated with magnesium or sodium. Forms hard scale in boilers with calcium. Causes bitter taste.
Chloride Cl	250 mg/l	Nearly all soils and rocks	Imparts, a salty taste. May increase the corrosive activity of water with calcium and magnesium.
Nitrate NO_3	45 mg/l	Nitrate fertilizers, organic matter, and sewage	Causes methemoglobinemia or infant cyanosis. Encourages growth of algae and other organisms.
Hardness $CaCO_3$	--	Alkaline earth minerals	Affects the lathering ability of soap. Gnerally objectionable for domestic use at hardness of more than 100 mg/l, but can be treated by softening.
Specific conductance	--	Dissolved mineral content of water	Measure of waters ability to conduct an electric current, thus measures the degree of ionization.
Dissolved solids	500 mg/l	Chiefly minerals dissolved from rocks and soils; organic matter; water of crystallization	Waters containing more than 1,000 mg/l of dissolved solids are unsuitable for many purposes.
pH	--	Acids, acid-salts, and free carbon dioxide lower the pH. Carbonates, bicarbonates, hydroxides, and phosphates raise the pH.	A pH of 7 indicates neutrality of a solution. Lower values of pH generally indicate more corrosiveness of water.
Temperature °C	--	Climatic conditions, pollution	Affects usefulness of water for many purposes. Important in fisheries rearing.

1/ Maximum concentrations as established by the U.S. Public Health Service.

Table 6. CHEMICAL ANALYSIS OF WATER FROM STREAMS

Chemical analyses made in field by U. S. G. S. personnel

BrS - Bright sun
PC - Partly cloudy

Stream	Location of sampling site	Sampled: Date (1969)	Sampled: Hour	Weather	Temperature, (°C): Air	Temperature, (°C): Water	Specific conductance Micromhos at 25°C	pH	Alkalinity	Non carbonate hardness	Dissolved solids	Bicarbonate HCO_3	Carbonate CO_3	Sulfate SO_4	Chloride Cl	Nitrate NO_3	Hardness $CaCO_3$	Dissolved oxygen	Remarks
									Dissolved constituents in milligrams per liter, except as indicated.										
Hazel Creek	NE NW sec. 1, T. 50 N., R. 34 W.	8-26	1730	BrS	--	12	195	7.6	98	0	127	119	0	3.0	1.2	0.3	93	9.4	Base flow, no rain for many days.
Huron River	NW NW sec. 35, T. 52 N., R. 30 W.	8-19	1530	BrS	17.5	20	100	7.8	54	0	65	66	0	3.0	1.0	.1	50	9.8	Base flow. Sampled between forks and bridge.
Peshekee River	SW NW sec. 26, T. 50 N., R. 31 W.	9-18	1030	PC	10.5	13	60	7.8	24	5	39	29	0	7.0	0	1.0	29	9.0	Base flow. Intermittent sun.
Silver River	SW NW sec. 18, T. 51 N., R. 31 W.	8-14	0915	BrS	--	19	115	8.5	—	--	--	--	--	—	—	—	65	9.2	Base flow, No appreciable rain for 4 days. Sampled downstream side of bridge.
Six Mile Creek	NW NW sec. 12, T. 50 N., R. 34 W.	8-28	1300	BrS	30	14	160	7.5	86	0	107	105	0	1.5	.8	.1	80	10	Base flow. Sampled 2' upstream from bridge site.
Slate River	SE NE sec. 8, T. 51 N., R. 31 W.	8-19	1400	BrS	18	18.5	115	7.5	56	0	75	65	0	3.0	1.0	.2	54	9.8	Base flow. Access on left bank.
Sturgeon River	SE NW sec, 8, T. 52 N., R. 33 W.	8-28	1030	PC	24.5	22.5	165	7.7	81	0	104	99	0	1.0	.5	.1	76	9.4	Base flow. Access 500 feet downstream from bridge.
Tioga River	SW NW sec. 8, T. 48 N., R. 32 W.	8-20	0930	BrS	15.5	15.0	83	7.1	42	0	54	51	0	.0	.5	.1	42	9.4	Base flow. Access upstream end of rapids in park, south of U. S. 41.

Table 7. CHEMICAL ANALYSIS OF WATER FROM LAKES

Chemical analyses made in field by U. S. Geological Survey personnel

Weather: BrS - Bright sun
PC - Partly cloudy

Lake	Location of sampling site	Sampled: Date (1969)	Sampled: Hour	Weather	Temperature, (°C): Air	Temperature, (°C): Water	Specific conductance Micromhos at 25°C	pH	Alkalinity	Non carbonate hardness	Dissolved solids	Bicarbonate HCO_3	Carbonate CO_3	Sulfate SO_4	Chloride CL	Nitrate NO_3	Hardness $CaCO_3$	Dissolved oxygen	Remarks
									Dissolved constituents in milligrams per liter, except as indicated.										
LAKES WITH OUTLETS																			
Craig Lake	SW NE sec. 28, T. 49 N., R. 31 W.	9-22	1100	BrS	—	18.0	50	6.7	5	3	32	6	0	11	1.0	0.1	8	8.5	No rain for past week. Outlet to Peshekee River tributary.
King Lake	SE NE sec. 27, T. 48 N., R. 33 W.	9-20	1015	BrS	14.0	13.0	50	6.9	7	7	—	9	0	8.0	.8	3.8	14	9.0	Suspended sediment in water.
Worm (Vermilac) Lake	NW SE sec. 24, T. 48 N., R. 34 W.	9-20	0930	BrS	12.0	14.0	50	6.8	8	7	—	10	0	6.0	1.0	1.4	15	9.5	No rain for past week.
Plumbago Creek	SW NE sec. 18, T. 49 N., R. 33 W.	9-10	1140	BrS	15.0	17.5	75	7.8	34	4	49	41	0	9.0	1.0	1.7	38	9.4	No rain since 9-8. Sampled at access site north of highway. Flow regulated.
Ruth Lake	SE NE sec. 18, T. 48 N., R. 31 W.	8-21	0900	BrS	17.0	20.5	50	6.9	14	4	29	17	0	.0	1.5	.0	18	8.6	No rain for many days. Outlet through George and Beauforc Lakes.
LAKES WITHOUT OUTLETS																			
Big Lake	NW SW sec. 28, T. 49 N., R. 34 W.	9-19	1230	BrS	11.4	20.0	50	5.9	2	1	—	2	0	17	0.0	0.2	3	9.0	Sampled at public access site.
Laws Lake	NW NW sec. 18, T. 50 N., R. 32 W.	9-22	1500	PC	—	18.5	90	7.9	55	0	58	67	0	8.0	.0	.4	48	9.5	Sampled at public access site.
Petticoat Lake	SW SE sec. 33, T. 48 N., R. 31 W.	8-21	1200	BrS	—	24.0	50	6.8	14	D	—	17	0	3.0	1.0	.1	14	8.6	Dutlet appears to have been blocked for a long period. Near shore water surface covered with algae.

Table 8. WELL YIELDS

Well number	Aquifer BR = *Bedrock* Gd = *Glacial drift*	Yield *gpm*	Drawdown *feet*	Duration of test *hours*	Specific capacity *gal/min/ft drawdown*
48N 31W 17-1	BR	4	67	1	0.06
35-2	Gd	6	61	10	.10
48N 34W 21-1	Gd	10	20	24	.50
49N 34W 14-1	Gd	115	32	5	3.60
51N 31W 8-1	BR	10	15	10	.66
51N 32W 8-1	Gd	30	15	2	2.00
8-2	Gd	20	52	2	.40
9-1	Gd	30	2	2	15.00
30-1	BR	3	85	2	.03
51N 33W 28-1	BR	5	30	2	.16
28-2	BR	5	50	2	.10
32-1	Gd	5	45	2	.11
51N 34W 5-1	BR	20	35	1	.57
36-1	Gd	20	5	4	4.00
52N 31W 32-1	BR	9	11	4	.81
52N 33W 2-2	BR	50	100	48	.50
14-1	BR	5	82	2	.06
14-2	BR	5	86	2	.06
14-3	BR	1.5	180	1	.01
27-1	BR	10	4	2	2.50
27-2	BR	9	26	4	.34
34-2	BR	10	20	2	.50

TECHNICAL STAFF
Department of Natural Resources
Geological Survey Division

Arthur E. Slaughter, *State Geologist and Chief*

Water and Environment Section
Stevens T. Mason Building
Lansing, Michigan 48926
Telephone (517) 373-7860

J. R. Byerlay, *Geologist and Supervisor*
R. P. Bissell, *Geologist*
W. A. Walden, *Geologist*
W. M. Iversen, *Geologist*
I. Pothacamury, *Geologist*

Upper Peninsula Office
201 State Office Building
Escanaba, Michigan 49829
Telephone (906) 786-0333

K. A. Gravelle, *Geologist and Supervisor*
D. R. Brackenbury, *Geologist*
J. L. VanAlstine, *Geologist*

TECHNICAL STAFF
United States Geological Survey
Water Resources Division
Michigan District

District Office - Lansing
2400 Science Parkway
Okemos, Michigan 48864
Telephone (517) 372-1910
Extension 561

T. R. Cummings, *District Chief*
R. L. Knutilla, *Assistant District Chief*
J. B. Miller, *Supervisory Hydrologist*
J. O. Brunett, *Hydrologist*
J. M. Ellis, *Hydraulic Engineering Technician*
R. L. Gordon, *Hydraulic Engineering Technician*
G. C. Huffman, *Hydraulic Engineering Technician*
R. L. LuVoy, *Hydrologist Aid*
G. L. Morin, *Hydraulic Engineering Technician*
J. O. Nowlin, *Hydrologist*
M. K. Rayburn, *Hydraulic Engineering Technician*
L. E. Stoimenoff, *Hydrologist*
F. R. Twenter, *Hydrologist*
C. R. Whited, *Hydraulic Engineering Technician*
J. L. Zirbel, *Hydraulic Engineering Technician*

Grayling Office
P. O. Box 485, Fish Hatchery
Telephone (517) 348-8291

D. Pettengill, *Supervisory Hydrologist*
H. L. Failing, *Hydraulic Engineering Technician*
J. C. Failing, *Hydraulic Engineering Technician*
N. L. Horning, *Hydraulic Engineering Technician*
R. W. Larson, *Hydraulic Engineer*

Escanaba Office
Room 205 State Office Bldg.
Telephone (906) 786-9714

G. C. Hulbert, *Supervisory Hydraulic Engineer*
M. J. DeGrand, *Hydraulic Engineering Technician*
C. J. Doonan, *Hydraulic Engineering Technician*
R. R. Eagle, *Hydraulic Engineering Aid*
C. L. Ebsch, *Hydraulic Engineering Technician*
L. B. Hough, *Hydraulic Engineering Technician*
J. L. Oberg, *Hydraulic Engineering Technician*

ITEMS IN POCKET

Plate 1. -- Hydrologic data of selected wells and topography of Baraga County, Michigan.

Plate 2. -- Geology and availability of ground water in Baraga County, Michigan.

ERRATA

During the time interval between the printing of plate 2 and final report preparation, certain changes in terminology by the U. S. Geological Survey made necessary the following corrections:

Plate 2

EXPLANATION: Change "SWAMP DEPOSITS AND RECENT ALLUVIUM," type 7 and 8, to read "SWAMP DEPOSITS AND HOLOCENE ALLUVIUM."

BEDROCK GEOLOGY: Change "MIDDLE PRECAMBRIAN (ANIMIKE) METAMORPHICS AND IRON FORMATION" to read, "MIDDLE PRE-CAMBRIAN (MARQUETTE RANGE SUPER-GROUP) METAMORPHICS AND IRON FORMATION."